SPECTROGRAPHIC OBSERVATIONS OF OMICRON ANDROMEDAE FROM 1967 TO 1976

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Abstract. The results of qualitative analysis and radial velocity (*RV*) determinations from 1967 to 1976 are given. These analyses show sometimes the presence of a thin variable shell also in the years 1967–1974, before the appearance of the envelope. Intensity variations of the metallic lines seem to indicate that in the same period changes of temperature and/or electron pressure may occur in the photospheric layers. In the period 1975–76, the considerable range of *RV* and the variability of the shell features show that the shell is rather active. Some conspicuous *RV* variations seem to be correlated to brightness changes. The *RV* do not confirm the periods suggested by the photometric observations. A periodogram analysis gives *RV* curves with a poor evidence of periodicity. However, the period $P = 1^{\mathrm{d}}.5845$ obtained from this analysis, close to that of Schmidt, seems to confirm Schmidt's hypothesis of a contact binary system. The periodogram analysis of the *RV* during the years 1900–1976 and some physical arguments, suggest a probable photospheric activity or an invisible companion with the observed shell period of 30 yr. The duplicity, suggested by Kříž and Harmanec (1975) for all the Be stars, could be yet questioned for *o* And.

1. Introduction

Several photometric observations suggested that the Be variable *o* And (HD 217 675) is actually a close binary system. Archer (1958, 1959), Schmidt (1959), Jackisch (1963), Olsen (1972), have proposed periods from $0^{\mathrm{d}}.79$ to $1^{\mathrm{d}}.60$; the observed amplitude variations are of the order of some tenths or hundredths of magnitude. However, all light curves are much perturbed. According to Plavec (1973), the configuration of the system could be the result of case *A* mass transfer leading to contact, and the envelope producing the shell spectrum would surround the whole system.

The duplicity of *o* And was questioned by Detre (1966). According to his opinion, 'the star, as a shell star, shows variations of some hundredths of magnitude, but it is not an eclipsing binary'.

Systematic spectrographic observations of *o* And began at the Merate Observatory in the year 1961. The results obtained for the period 1961–1967 were given by Pasinetti (1967, 1968 hereafter referred to as Paper I; in the latter paper a more complete series of references is reported), Galeotti and Pasinetti (1968a, b). In Paper I we suggested that the new major shell of *o* And should reappear in 1976. The observations of July 1975, reported by Koubský (1975a), Bopp (1975), Peters and Polidan (1975), Stickland (1975), have confirmed this forecast, the periodicity of the

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shell and the period (Fracassini and Pasinetti, 1975a) suggested by Schmidt (1959) and by Pasinetti (1967, Paper I). The duration of the shell is of about 5 yr, the period without the shell is of about 24 yr. In 1975 we suggested to a photometric group of the Merate Observatory to perform systematic photoelectric observations of *o* And in the *UBV* system. Preliminary results have been reported by Bossi *et al.* (1976).

Polarization measures of *o* And were made by Coyne (1976). Recent results on the *UV* spectrum have been published by Lamers and Snijders (1975).

Citterio *et al.* (1976), on 2 and 3 October, 1975, have kindly observed on request this star in the photometric system *J*, *H* and *K*. Their results are the following: $[J]=3.69\pm0.04$, $[H]=3.73\pm0.03$, $[K]=3.74\pm0.03$, $V-J=-0.26\pm0.1$, $V-K=-0.31\pm0.1$; however the uncertainties in the determination of A_V do not allow to question the presence of a color excess at 1.25 and 2.2 μ.

The present study deals with a qualitative analysis of the spectra from 1968 to 1976, with radial velocity determinations (*RV*) from 1967 to 1976 and with a survey of the periods derived from the photometric measures. Finally we have performed a periodogram analysis.

2. Material and Methods

The observations were performed on the 100 cm Zeiss telescope and on the 137 cm Ruths telescope of the Merate Observatory, with the Zeiss prism spectrograph (35 Å mm^{-1} at Hγ). Table I lists the data of the spectra. The columns are self explanatory.

For the *RV* determinations, the spectra were measured with the visual digitized comparator of the Merate Observatory. The shifts are measured by a Heidenhain

TABLE I

List of the plates from 1967 to 1976

Number Sp.	Date	Spectral range	Heliocentric Julian Day 2 400 000+
2455	1967 – 12 Sept.	*V*	39 746.319
2458	12	*V*	9 746.381
2461	12	*V*	9 746.434
2470	26	*V*	9 760.422
2478	18 Oct.	*R*	9 782.427
2485	19	*R*	9 783.392
2487	19	*V*	9 783.434
2696	1968 – 19 Nov.	*V*	40 180.354
2806	1969 – 23 Sept.	*V*	488.375
2807	23	*R*	488.406
2861	1970 – 21 Sept.	*R*	851.304
2862	21	*V*	851.328
2874	29	*R*	859.302

Table I (Continued)

Number Sp.	Date	Spectral range	Heliocentric Julian Day 2 400 000+
2875	1970 – 29 Sept.	*V*	40 859.318
3040	1971 – 31 Aug.	*V*	41 195.378
3041	31	*V*	1 195.389
3042	31	*R*	1 195.414
3043	31	*R*	1 195.434
3049	1972 – 14 Dec.	*V*	1 666.323
3050	14	*V*	1 666.331
3051	14	*V*	1 666.341
A 1451	14	*R*	1 666.347
3052	14	*R*	1 666.356
A 1452	14	*V*	1 666.358
A 1453	14	*V*	1 666.376
A 1461	16	*R*	1 668.218
A 1462	16	*R*	1 668.221
A 1463	16	*R*	1 668.228
ZCM 326	1973 – 2 Sept.	*V*	1 928.414
334	4	*R*	1 930.467
343	2 Oct.	*V*	1 958.307
344	2	*V*	1 958.312
536	30	*V*	1 986.387
537	30	*V*	1 986.400
538	30	*V*	1 986.413
568	29 Nov.	*R*	42 016.348
733	1974 – 27 Sept.	*V*	2 318.365
734	27	*V*	2 318.377
735	27	*R*	2 318.399
741	24 Oct.	*R*	2 345.385
742	24	*V*	2 345.410
839	1975 – 23 July	*V*	2 617.473
840	23	*R*	2 617.497
856	17 Sept.	*V*	2 673.412
857	17	*R*	2 673.438
A 2046	20	*R*	2 676.443
A 2047	20	*R*	2 676.457
ZCM 858	2 Oct.	*R*	2 688.375
859	2	*V*	2 688.401
860	2	*V*	2 688.416
861	7	*R*	2 693.328
862	14	*R*	2 700.405
863	20 Nov.	*R*	2 737.241
864	20	*R*	2 737.270
865	20	*R*	2 737.303
866	20	*R*	2 737.335
867	20	*R*	2 737.363
868	20	*R*	2 737.393
869	20	*R*	2 737.422
870	21	*R*	2 738.230
871	21	*R*	2 738.254

Table I (*Continued*)

Number Sp.	Date	Spectral range	Heliocentric Julian Day 2 400 000+
ZCM 872	1975 – 22 Nov.	*R*	42 739.220
873	22	*R*	2 739.260
874	23	*R*	2 740.228
875	23	*R*	2 740.251
876	24	*R*	2 741.217
877	24	*R*	2 741.241
878	25	*R*	2 742.322
879	25	*R*	2 742.366
880	28	*R*	2 745.234
881	29	*R*	2 746.213
882	29	*R*	2 746.238
883	4 Dec.	*R*	2 751.228
884	4	*R*	2 751.269
885	10	*R*	2 757.266
886	11	*R*	2 758.204
887	11	*R*	2 758.237
888	12	*R*	2 759.205
889	12	*R*	2 759.232
890	22	*R*	2 769.257
891	22	*R*	2 769.289
892	29	*R*	2 776.209
914	1976 – 8 Jan.	*R*	2 786.225
915	8	*R*	2 786.250
916	22	*R*	2 800.228
917	28	*R*	2 806.250

Spectral range: $V = \lambda\lambda$ 3600–5000; $R = \lambda\lambda$ 3600–6600. Symbol A: spectra taken with the 120 cm telescope of the Asiago Observatory with the Galileo prism-spectrograph (camera III: 42 Å mm^{-1} at Hγ). Those of 1972 were taken by Dr M. Barbon.

grating (1 μ accuracy). The *RV* have been computed on the 1106 Univac computer of the University of Milan.

3. Qualitative Analysis

In the present paper a concise qualitative analysis of all the spectra from 1968 to 1976 is given. As it is known, this analysis is useful for the correct interpretation of the *RV* curves of Be stars.

PERIOD 1968–74, BEFORE THE REAPPEARANCE OF THE SHELL

As remarked by Pasinetti (Paper I, 1967) for the period 1961–1967, conspicuous variations occur in the Balmer lines: absorption cores indicating at least a thin shell, are sometimes visible; in other periods they weaken or disappear. Variations of intensity occur in the metallic lines. The photospheric lines are broadened by the high rotational velocity (360 km s^{-1}, Slettebak, 1952).

1968. The absorption cores of the Balmer lines are well visible. In particular, Hβ shows a remarkable core sharper and deeper than that observed in 1967. The cores of the higher members are progressively sharper (until Hδ) in respect to those of the preceding years. Moreover, as we have remarked (Paper I), the cores become deeper and sharper, progressively from the leading to the higher members of the Balmer series, during the phase of strengthening of the cores; the reverse occurs when they weaken. He I 14 and Mg II 4 are very weak.

1969. Hα shows a very sharp core; the aspect of the other Balmer lines is nearly similar to that of 1968. He I, Mg II, very weak.

1970. The spectrograms of 21 and 29 September are different: the absorption cores and the lines of Mg II are not visible on 21 September; the cores of Hα and Hβ and Mg are visible and He stronger on 29 September. According to Koubský (1975b) the spectrograms show normal B type spectrum from 1970 to 1972.

1971–1972. Normal spectra. He and Mg very weak and variable.

1973. The Balmer lines have a variable aspect. On 2 and 4 September the Balmer lines do not show any core; Mg II is not visible. On 30 October Mg II is visible but very weak. On 29 November, the spectrum shows a weak core in Hα and probably also in Hβ, Mg II is present. He I variable and very weak.

1974. The spectra are remarkably changed. Sharp and deep absorption cores are present in Hα, Hβ, Hγ; the intensity of the cores is progressively weakening until Hε–H8. The cores of October are probably stronger than those of September. Hα and Hβ have asymmetric profiles, steep on the shortward side. Mg II and He I are stronger than in the preceding years. We remark that the cores observed in 1974 are deeper than those of 23 July, 1975 (reappearance of the shell). Moreover on the spectra of 24 October we found the lines of Fe II 42 at λλ 5818.43, 4923.92, characteristic of the shell spectrum.

PERIOD 1975–1976, REAPPEARANCE OF THE SHELL

In July 1975 the shell spectrum has appeared. It shows shortward (*V*) and longward (*R*) emissions in Hα, absorption cores in the Balmer lines and weak metallic absorption lines. Some Balmer absorption lines (especially Hγ), have asymmetric profiles, steep on the longward side with a wing tailing off to shorter wavelengths. The shell period of about 30 yr (Fracassini and Pasinetti, 1975a), is consistent with the spectral type of this star (Delplace and Hubert, 1975).

From July 1975 to January 1976, the intensities of the shell features are sometimes variable with a very short time scale (one day). Our spectra of 23 July show: a weak absorption feature partly filled by the emission, in Hα (dispersion at Hα about 200 Å mm^{-1}); absorption cores of the first Balmer lines less deep than those observed in 1974, weak metallic absorption lines. Among them, Fe II lines of the multiplets 27, 37, 38, have been identified. Successively, the deep absorption feature of Hα appeared clearly flanked by the *V* and *R* emission components. Variations of the metallic lines were noted: some lines were weakened, others, such as Fe II 40, 42, had appeared.

The inspection of the spectra shows that the intensities of the Hα *V* and *R* emissions, are variable. However no periodicity has been established from this preliminary analysis. The outstanding measures on microphotometric tracings will ascertain an eventual periodicity.

On 4 December considerable changes occurred in the spectra. The Balmer cores, strengthened at the end of November, became very sharp and deep, and the intensity of the metallic lines increased. We supposed (Fracassini and Pasinetti, 1975b) that the major shell was developing. However, our observations of 10 December, and those of Koubský (1975c) have not confirmed such a hypothesis. Evidently the time scale of the variations was very short in this period, one day according to Bolton and Gulliver (1976).

TABLE II

Spectral identifications

Hα	6562.817	H10	3797.900
Hβ	4861.332	H11	3770.632
Hγ	4340.468	H12	3750.154
Hδ	4101.737	H13	3734.370
Hε	3970.074	H14	3721.940
H8	3889.051	H15	3711.973
H9	3835.386	H16	3703.855
He II 11	5875.989 }	He I 53	4143.759
	5875.650 }	He I 18	4026.362 }
	5875.618 }		4026.189 }
He I 48	4921.929	He I 55	4009.270
He I 14	4471.477 }	He I 58	3926.530
	4471.688 }	He I 22	3819.761 }
He I 51	4387.928		3819.606 }
C II 6	4267.270 }	Fe II 210[a]	6677.330
	4267.020 }	Fe II 40[a]	6369.450
		Fe II 200[a]	6305.318
		Fe II 49[a]	5276.090
Na I 1[a]	5895.923	Fe II 49[a]	5197.569
Na I 1[a]	5889.953	Fe II 42[a]	5169.030
		Fe II 42[a]	5018.434
Mg II 16[a]	6346.670	Fe II 42[a]	4923.921
Mg II 4	4481.327 }	Fe II 38[a]	4583.829
	4481.129 }	Fe II 37[a]	4555.590
		Fe II 38[a]	4549.467

Table II (Continued).

Si II 3	4130.884	Fe II 38[a]	4522.634
Si II 3	4128.053	Fe II 37[a]	4515.337
		Fe II 37[a]	4491.401
		Fe II 27[a]	4385.381
Ca II 1	3933.664	Fe II 27[a]	4351.764
		Fe II 27[a]	4233.167
Ti II 31[a]	4468.493		

[a] Shell metallic lines.

Table II reports the lines of the star and of the shell identified with certainty in our spectra. Not all shell lines are always present in the period 1975–1976, owing to the intensity variations of the metallic lines. We have compared these identifications with those of some high dispersion spectra. We shall publish the results of this analysis separately.

4. Radial Velocities

The values of *RV* from 1967 to 1976 are reported in the Appendix. We must note that the measures of the *RV* are difficult owing to the high rotational velocity which broadens the lines.

Hydrogen and metallic lines of the star and of the shell were measured. The *RV* derived from the Balmer lines are perturbed by the presence of the cores; therefore these measures may reflect the dynamics of an eventual mass loss from the star and the dynamics of the shell. The helium lines give the photospheric *RV*.

The mean errors of the *RV* range from about 16 km s^{-1} for Hα to 4 km s^{-1} for H8. The observed *RV* variations are largely higher than the error bars.

Although it should not be correct, owing to the Balmer progression, we report in Figure 1 the averaged *RV* (Hα–H8), to give the global trend from 1967 to 1976. Figures 2 and 3 represent the *RV* of Hγ respectively for the same years and for the period 1975–76. The latter figure, with more detailed scale of abscissae allows to follow the *RV* variations day by day. In Figure 4 the *RV* derived from the metallic lines are reported.

An attempt to check the periods derived from the photoelectric measures has been made with our *RV*. The periods suggested by Schmidt (1959), Archer (1958, 1959), Jackisch (1963) and Olsen (1972), were considered. For example, we report in Figure 5 the check for the period by Schmidt.

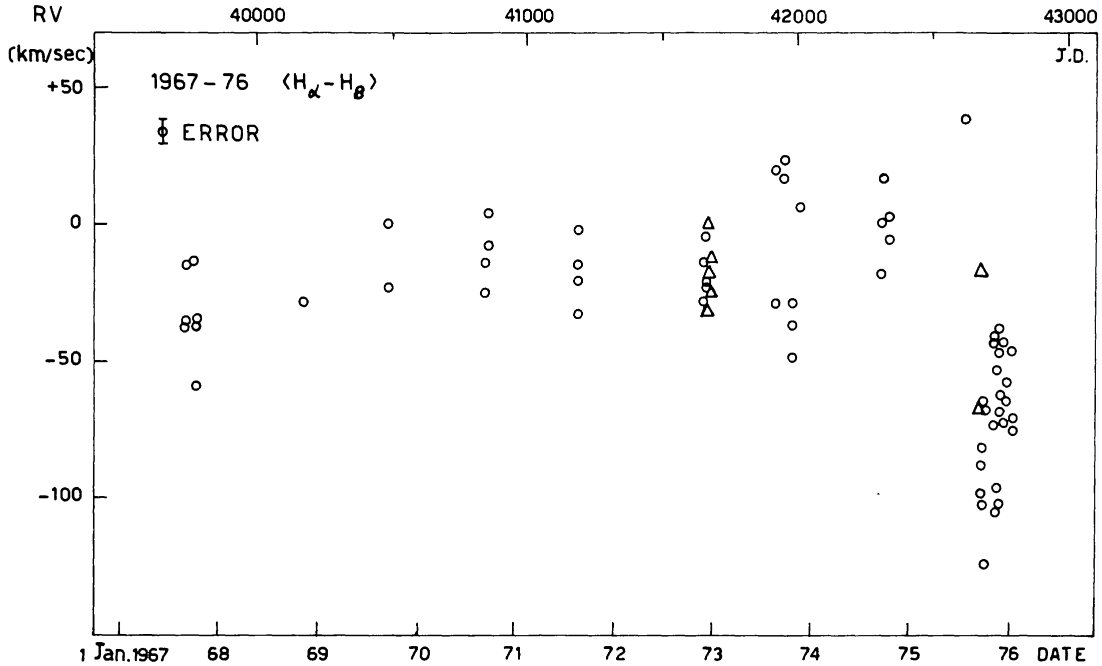

Fig. 1. Averaged radial velocities from 1967 to 1976. Open circles: values derived from spectra taken at Merate. Triangles: spectra taken at Asiago.

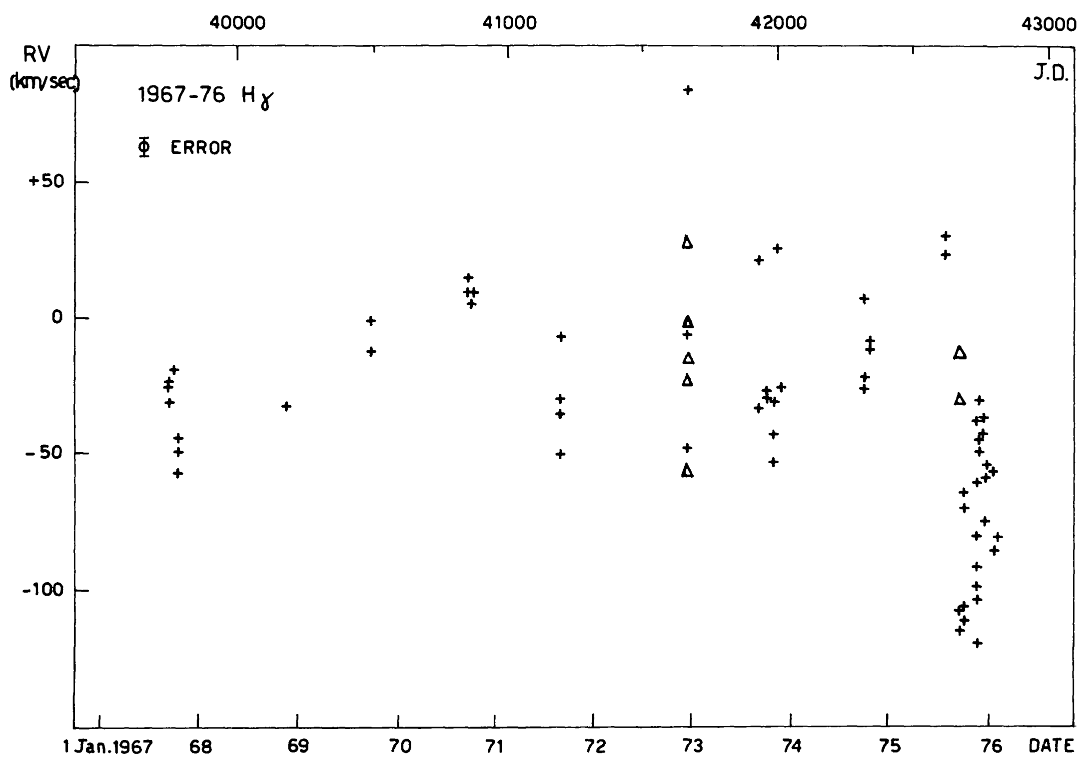

Fig. 2. Radial velocities from 1967 to 1976 derived from Hγ. Crosses: spectra of Merate. Triangles: spectra of Asiago.

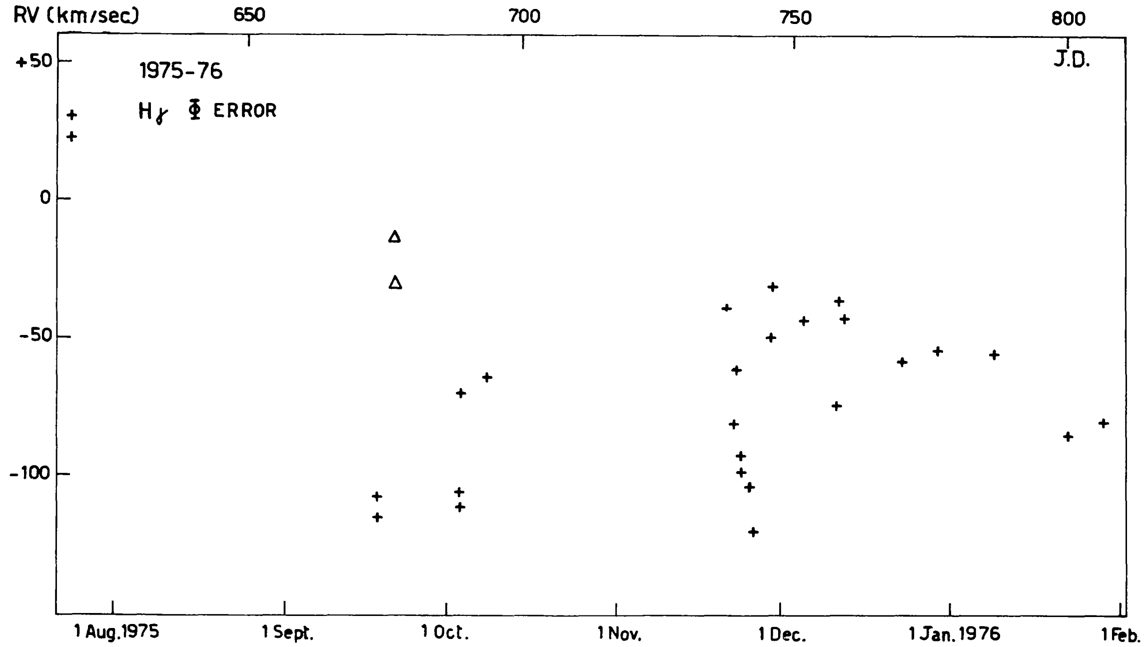

Fig. 3. Radial velocities of Hγ for the period 1975–76. For the symbols see Figure 2.

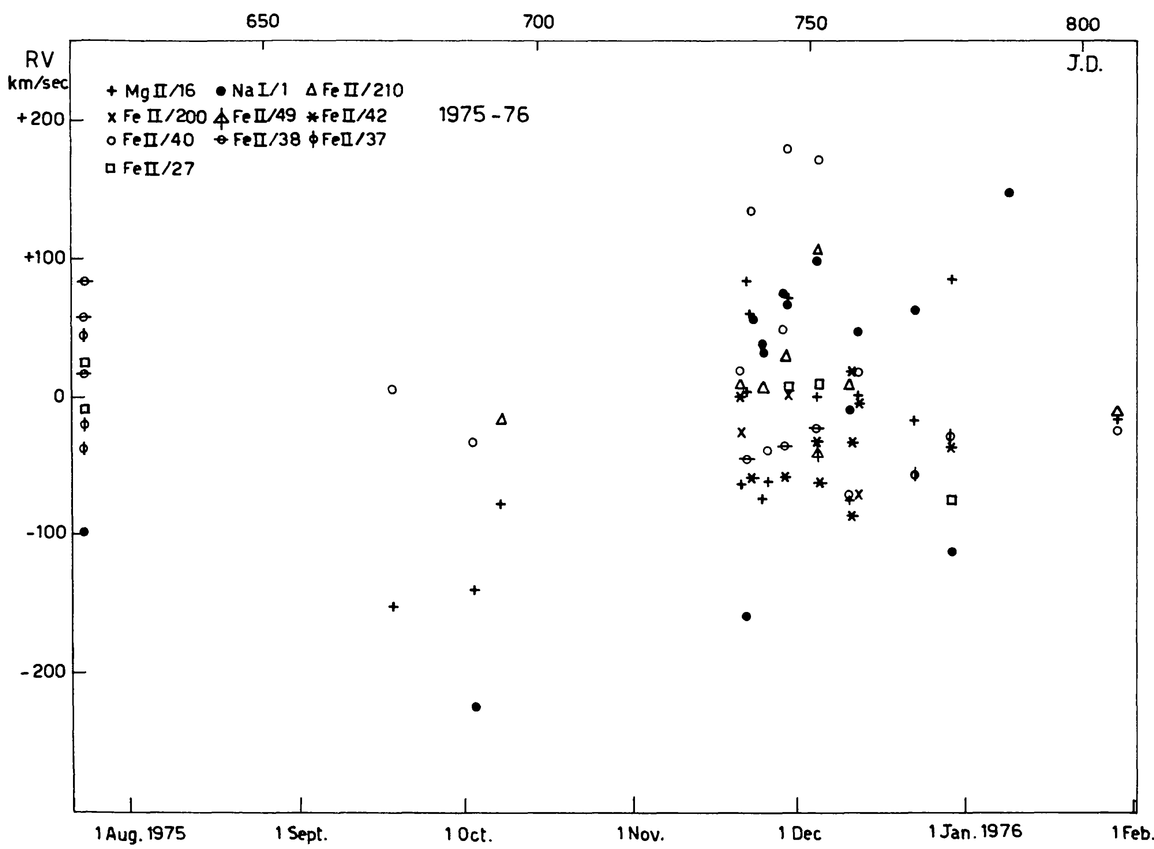

Fig. 4. Radial velocities of metallic lines.

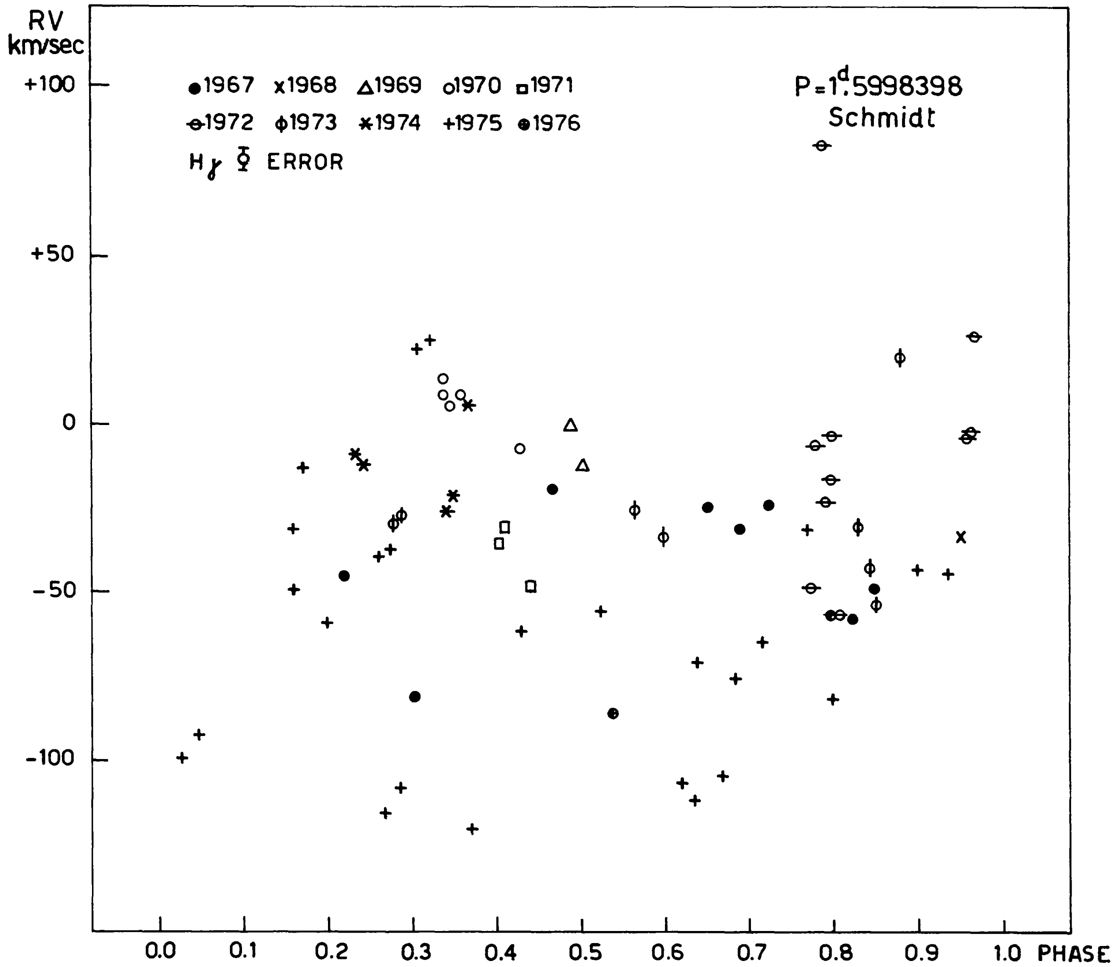

Fig. 5. Radial velocities of Hγ according to the period suggested by Schmidt.

5. Analysis of the Periods

A periodogram analysis was made with our *RV* values using the method proposed by Lafler and Kinman (1965). Three ranges of periods have been examined:

(a) 0ᵈ04–2ᵈ0: the typical periods of stellar rotation for stars of early spectral types, of possible pulsation, and the periods suggested by the photometric observations.

(b) 20^d–80^d: the orbital periods of other systems which could be similar to *o* And (for example the Be star 4 Her studied by Harmanec *et al.*, 1976).

(c) 10^y–50^y: the probable period for the shell of a B6 star (Delplace and Hubert, 1975).

In the cases (a) and (b) we have performed the computations separately for the Hβ and Hγ lines. In the last case we have utilized our *RV* values from 1961 to 1976 and those found in the literature from 1900. These values are not homogeneous, but they are nearly well comparable for the analogous dispersion of the spectra. Further, when possible, the values of *RV* adopted are averaged from Hα to H8 for single spectra, and from all the spectra for each month. For the cases (a) and (b), we have considered separately the values of the years 1967–1976, 1967–1974, and 1975–1976.

The periodogram analysis has indicated the following periods: case (a), $P = 1\overset{d}{.}5845$, near to that suggested by Schmidt (1959); case (b), $P = 72\overset{d}{.}3145$; case (c), $P_1 = 23\overset{y}{.}4995$, $P_2 = 40\overset{y}{.}2117$. For the case (c), the period P_1 has been chosen for the reasons explained in Section 6. Table III reports the RV from 1900 to 1976 used in this analysis. The

TABLE III

Radial velocities of *o* And from 1900 to 1976

Date	Julian Day	Phase	RV	Ref.
1900 Oct.	2 415 302	0.0000	−13.0	(1)
Dec.	5 371	0.0080	−14.7	(1)
1901 June	5 561	0.0303	−22.6	(1)
Aug.	5 609	0.0359	−11.3	(1)
1902 Aug.	5 973	0.0782	−18.7	(2)
Sept.	5 999	0.0813	−14.2	(2)
Sept.	6 002	0.0817	−16.5	(1)
Nov.	6 059	0.0883	−13.3	(1)
1905 July	7 041	0.2027	−28.5	(2)
Aug.	7 079	0.2071	−16.3	(2)
1906 Nov.	7 522	0.2587	−16.5	(3)
1907 Aug.	7 809	0.2922	−11.2	(3)
Sept.	7 823	0.2938	−8.8	(3)
Nov.	7 895	0.3022	−13.6	(3)
1908 June	8 105	0.3268	−13.7	(3)
July	8 133	0.3300	−15.1	(3)
Aug.	8 173	0.3346	−15.8	(3)
Sept.	8 203	0.3380	−5.2	(2)
Nov.	8 253	0.3440	−8.8	(3)
1909 Aug.	8 550	0.3785	−7.2	(3)
Sept.	8 559	0.3795	−9.3	(3)
1910 July	8 874	0.4162	−9.7	(3)
Sept.	8 936	0.4234	−8.2	(3)
Oct.	8 965	0.4262	−9.5	(3)
1911 June	9 218	0.4564	−13.2	(3)
Aug.	9 264	0.4618	−11.9	(3)
Sept.	9 290	0.4648	−23.3	(3)
Oct.	9 338	0.4704	−12.4	(3)
1912 July	9 590	0.4997	−40.5	(3)
Sept.	9 653	0.5070	−12.7	(3)
Oct.	9 692	0.5116	−17.8	(3)
1928 Sept.	2 425 492	0.1873	−30.0	(4)
1929 Aug.	5 829	0.2266	−8.0	(4)
1931 Feb.	6 386	0.2915	−14.0	(4)
1949 Dec.	2 433 281	0.0948	−20.2	(5)
1950 Aug.	3 506	0.1210	0.8	(5)
1951 Aug.	3 888	0.1655	−5.0	(5)
1952 Sept.	4 262	0.2091	−12.5	(5)

Table III (*Continued*)

Date	Julian Day	Phase	*RV*	Ref.
1953 July	2 434 562	0.2440	−10.1	(5)
1961 Sept.	7 566	0.5940	7.3	(6)
1961 Oct.	7 595	0.5973	−21.9	(6)
1962 Aug.	7 888	0.6317	−28.1	(6)
Sept.	7 920	0.6353	−27.8	(6)
Oct.	7 958	0.6397	−34.9	(6)
Nov.	7 985	0.6428	−37.7	(6)
1963 Jan.	8 045	0.6498	−46.2	(6)
1964 July	8 594	0.7138	−47.8	(6)
Sept.	8 657	0.7211	−44.8	(6)
1965 Nov.	9 080	0.7704	−40.6	(6)
Dec.	9 108	0.7736	−15.3	(6)
1966 Sept.	9 391	0.8066	−44.8	(6)
Dec.	9 480	0.8169	−40.5	(6)
1967 Sept.	9 750	0.8484	−25.3	(7)
Oct.	9 783	0.8523	−43.8	(7)
1968 Nov.	2 440 180	0.8985	−28.4	(7)
1969 Sept.	488	0.9344	−15.9	(7)
1970 Sept.	855	0.9772	−10.8	(7)
1971 Aug.	2 441 145	0.0168	−17.8	(7)
1972 Dec.	1 666	0.0717	−17.4	(7)
1973 Aug.	1 929	0.1023	−4.2	(7)
Sept.	1 972	0.1076	−15.0	(7)
Oct.	2 016	0.1124	6.1	(7)
1974 Sept.	2 318	0.1476	−0.5	(7)
Oct.	2 345	0.1508	−1.4	(7)
1975 July	2 617	0.1825	−36.7	(7)
Sept.	2 675	0.1892	−67.7	(7)
Oct.	2 691	0.1912	−90.0	(7)
Nov.	2 738	0.1969	−69.2	(7)
Dec.	2 762	0.1994	−57.8	(7)
1976 Jan.	2 797	0.2035	−63.8	(7)

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phases of the third column have been computed with the period $P = 23\overset{d}{.}4995$ and the epoch 2 415 302.84.

6. Discussion

The Figures 1–4 show a considerable range of RV at one time. This range is real, and indicates some activity also in the years without the major shell. In particular, in the years 1975–1976 the RV show a rather active shell. The observed asymmetry of some Balmer lines profiles is in agreement with the Balmer progression, as Underhill (1966, p. 232) pointed out. We remember that the RV of the photospheric layers is about -14 km s^{-1} (Hoffleit, 1964). This mean value has been detected in the years 1970–1973, in which the spectrum was nearly normal.

In the Figures 1 and 2 we can see a general increase of the RV from 1967 to 1974 and a strong decrease in the period 1975–1976. In the period 1975–1976, the RV derived from the Balmer lines are mostly negative with the exception of the values of 23 July, those derived from the metallic lines are either negative or positive. The latter fact, in agreement with the theories on circumstellar matter (Huang, 1973), seem to indicate that some matter is falling into or/and escaping from the star.

The hydrogen RV rise abruptly from the minima values reached on 25 November, to higher values of 28–29 November, 4 December (Figure 3), in agreement with the remarkable spectral variations pointed out in the qualitative analysis (see Section 3). No significant changes have been remarked in the metals RV, with exception of Fe II 40, observed on 29 November and 4 December.

Unfortunately we have no observations for the period 29 October–10 November, when a brightness decrease occurred (Bossi *et al.*, 1976). Nevertheless, we can notice that before and after these dates, the RV of the first Balmer lines and of the metals increased remarkably from 2, 7, 14 October to 20 November. The decrease of the RV observed in the period 20–25 November, corresponds to a brightness increase. The higher values of the RV of 28–29 November and 4 December, correspond to a brightness decrease (Bossi *et al.*, 1976, Figure 7), in agreement with the preceding remarks for the period October–November.

We can summarize the results of our qualitative analysis and of the RV as follows:

(1) The intensity variations of the photospheric He I and Mg II lines observed in the period of our observations (see Section 3) may indicate temperature and/or electron pressure changes in the photospheric layers.

(2) All the results reported in the present section seem to indicate oscillatory motions of the thin shell in the years preceding the reappearance of the major shell (1967–1974).

(3) The abrupt strong negative RV in 1975 disclose the ejection of the envelope.

(4) The irregular changes day by day, hour by hour (observed during 6 h on 20 November, 1975), of the RV, indicate irregular motions of masses of gas.

(5) The comparisons between the brightness variations and the RV changes, reported above, seem to suggest that matter motions may be fairly well correlated with the brightness variations. Once more we point out the importance and necessity of simultaneous photoelectric and spectroscopic observations during the shell phase.

In our observations, the separation between the V, R emission components of Hα, changes from a minimum value of 355 km s^{-1} on 4 December to a maximum of 607 km s^{-1} on 11 December. More detailed results on the emission components obtained from high dispersion spectrograms, will be published in a forthcoming paper.

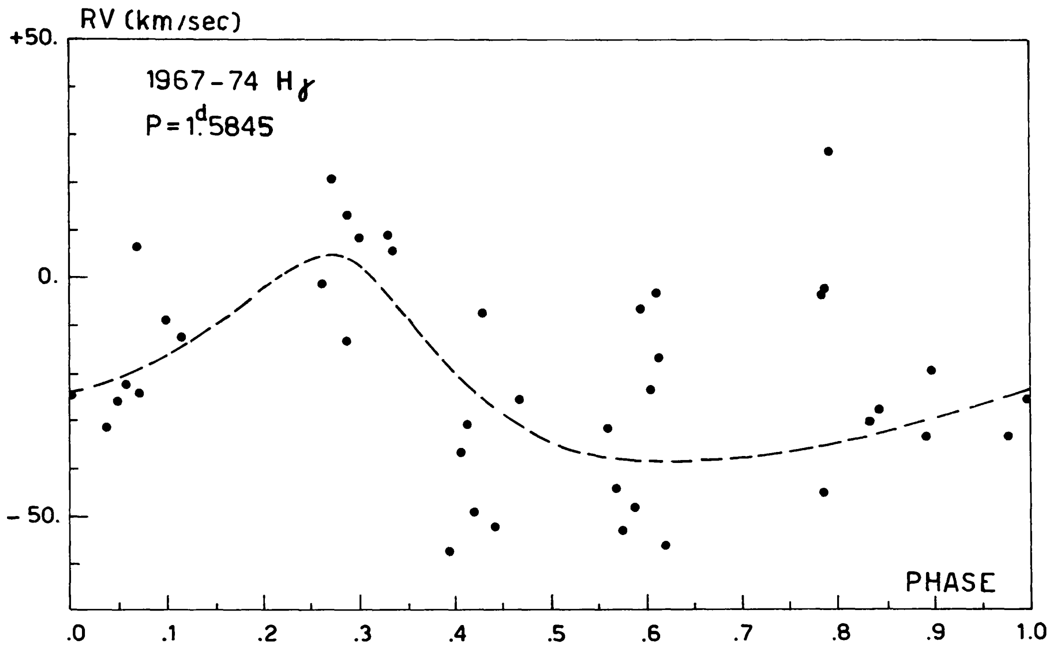

Fig. 6. Radial velocities of Hγ according to the period $P = 1^d\!.5845$, epoch 2 439 746.315 3 (years 1967–74).

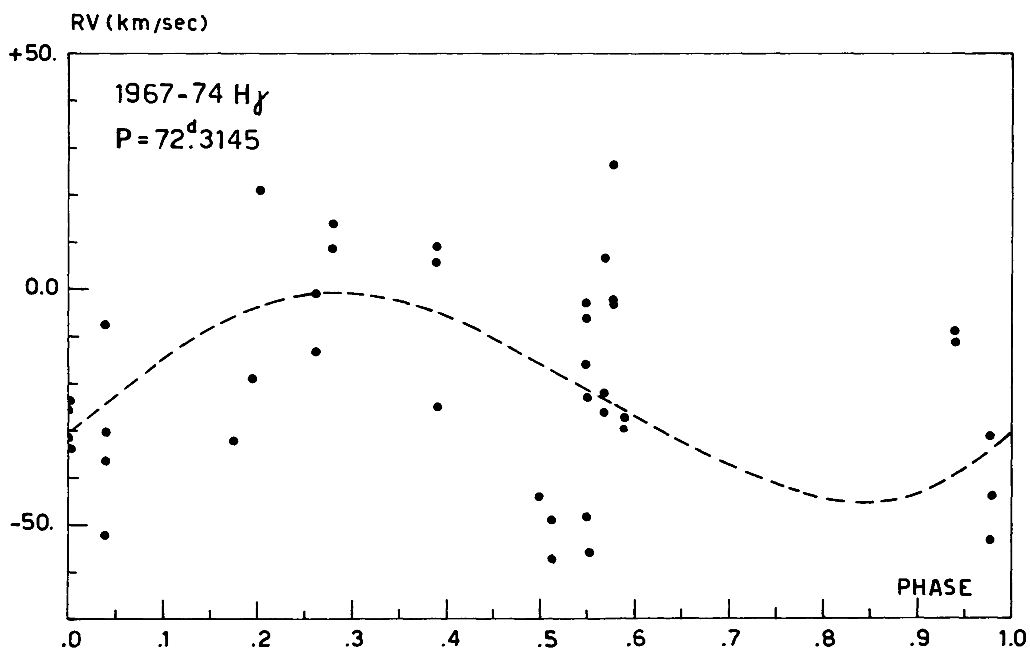

Fig. 7. Radial velocities of Hγ according to the period $P = 72^d\!.3145$, epoch 2 439 746.315 3 (years 1967–74).

From the analysis of the *RV* versus the phases computed with the photometric periods (see for example Figure 5), no periodical behaviour has been found.

RV curves have been plotted according to the more probable periods given by the periodogram analysis. Figures 6 and 7 show the results for Hγ respectively for $P = 1^d.5845$ and $P = 72^d.3145$, Figure 8 gives the behaviour of the averaged *RV* (found in the literature) versus the phases for $P = 23^y.4995$. The curves of Figures 6 and 7 show a poor evidence of these periods. However, considering in detail the Figure 6, we can remark that the more scattered *RV* values correspond to the year 1972 (phases ~0.6, 0.8) when the Hγ had a considerable scattering of *RV* (see Figure 2); the most scattered values at the phases 0.39 and 0.07 correspond to the years 1967, 1974, when some activity of the thin shell was observed. The value $P = 1^d.5845$ deduced from our *RV*, close to that found photometrically by Schmidt (1959), and of about the same order of the rotational period of this star, makes more tempting the hypothesis of Schmidt: a contact binary system, with highly deformed components.

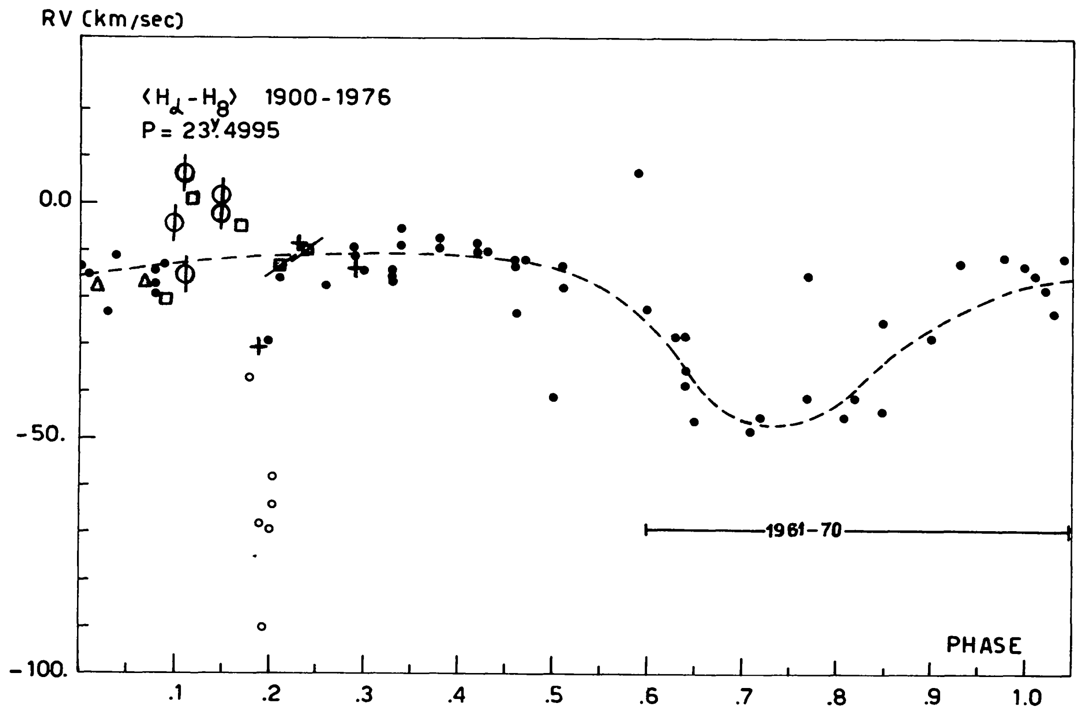

Fig. 8. Averaged radial velocities according to the period $P = 23^y.4995$, epoch 2 415 302.84 (years 1900–1976). ○ values of 1975–76 corresponding to the envelope ejection; ● 1900–1912; + 1928–31; □ 1949–51; ⊠ 1952–53; ● ● ● ● 1961–70; △ 1971–72; ϕ 1973–74.

Considering in detail the Figure 7, the scattered *RV* values at the phases 0.55–0.60, correspond to the year 1972; however the value of the dotted curve (fitted by least squares), at these phases, is in good agreement with the averaged value deduced from Figure 2 at the corresponding date. Of course, the branch of the dotted curve between phases 0.6–0.9 must be considered a pure extrapolation owing to the gap of data. Finally, the most scattered values at the phases 0.51 and 0.94, correspond to the years 1967, 1974 of the thin shell activity, as remarked for Figure 6. No reliable curves have been obtained with the *RV* values of the period 1975–1976; however the periodogram analysis gives a more probable period $P = 1^{d}.5894$, even closer to that of Schmidt.

The periodogram analysis of the case (c) suggested two periods $P_1 = 23^{y}.4995$ and $P_2 = 40^{y}.2117$; but the trend of these periodograms has shown a better reliability for the period P_1. Figure 8 shows a good fitting of the *RV* from 1900 to 1976. The period $P = 23^{y}.4995$ is nearly equal to the interval between the end and the beginning of a new shell ('intershell period'). The most dispersed values from the curve are represented by the values of 1975–1976 (open circles) corresponding to the envelope ejection. The values reported by Slettebak (1954) for the years 1949, 1950, 1951 (shell phase) respectively at the phases 0.09, 0.12, 0.17, do not scatter greatly from this curve. However the shell phase had begun in 1946 and the envelope could be in a nearly steady state. We must remark that the minimum between the phases 0.65–0.85 is given only by the years 1962–1966; therefore we cannot know if this phenomenon is recurrent or characteristic only of this period. The mean *RV* of the curve before and after the minimum is nearly equal to the *RV* of the star. We remark also that the values at the phases 0.11, 0.15, 0.61, 0.77, which scatter from the curve, correspond respectively to the years 1973, 1974, 1961, 1966, for which the qualitative analysis has shown some variations or deep absorption cores in the spectra.

The minimum falls between the years 1962–1966, therefore it has occurred at about the middle of the intershell period (1952–1975). In the years 1963–1965, a normal *B* type spectrum without shell characteristics was observed (see also Olsen, 1972). Instead, as we have pointed out in Section 4, in the other years when the Balmer lines show the cores, the *RV* are perturbed by the presence of the shell.

The minimum of the *RV* may support the hypothesis that the photospheric layers are undergoing some perturbations. These perturbations are also confirmed by the observed intensity variations of the photospheric metallic lines.

In Figure 8 one can see two probable periodic phenomena: (1) an activity of the photosphere, i.e., negative and positive *RV* fields; (2) ejection of the envelope. However, the period of 23 yr suggested by the periodogram analysis, is not in phase with the period of the shell ($\sim$30 yr). This difference could be due to the lack of suitably spaced measures of *RV* from 1900 to 1960 and in particular to the lack of *RV* in the shell period 1916–1921 (Paper I, Figure 1). Still the possibility of long-term periodic changes of the *RV* was pointed out by McLaughlin (1961). Therefore we have considered the fundamental shell period of about 30 yr, confirmed by the observations, and we have plotted the *RV* of Figure 8 according to this period.

From this arrangement the following more suitable features could result: a good separation ($\Delta\varphi \simeq 0.35$, about 10.5 yr) between the minimum of the photospheric *RV* and the ejection of the envelope; an equal period for these two phenomena. Hence, if the utilized data are proper for a long-period analysis, the following conclusions could be drawn: (1) the photosphere undergoes some activity with the same period of the shell; (2) the ejection of the envelope occurs at the maximum of the *RV*. The atmospheric activity could be connected with the thermal instability of the star's core (Kříž and Harmanec, 1975, p. 66).

Of course, these curves could suggest also the presence of an invisible companion.

7. Conclusions

The qualitative analysis of the spectra and the *RV* show that a thin variable shell is sometimes present also in the years 1967–1974, before the appearance of the envelope. Intensity variations of the metallic lines seem to indicate that in the same period changes of temperature and/or electron pressure may occur in the photospheric layers. In the period 1975–1976, the considerable range of the *RV* and the variability of the shell features show that the shell is rather active. Some conspicuous *RV* variations seem to be correlated to brightness changes.

The *RV* curves do not confirm the periods suggested by the photometric observations. A periodogram analysis gives *RV* curves with a poor evidence of periodicity. However, the period $P = 1\overset{d}{.}5845$ obtained from this analysis, close to that of Schmidt, seems to confirm Schmidt's hypothesis of a contact binary system. The periodogram analysis of the *RV* during the years 1900–1976 and some physical arguments, suggest a probable photospheric activity or the presence of an invisible companion with the observed shell period of 30 yr.

The duplicity, suggested by Kříž and Harmanec (1975) for all the Be stars, could be yet questioned for *o* And.

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Appendices

APPENDIX I

Radial velocities of hydrogen lines: missing values are due to limited spectral range of the plate

Number Sp.	Hα	Hβ	Hγ	Hδ	Hε
2455		−43.1	−24.9	8.1	−74.7
2458		−47.2	−30.8	−20.8	−41.9
2461		−13.0	−23.5	14.3	−15.9
2470		−30.0	−18.8	−0.7	−7.0
2478		−67.3	−44.6	−66.5	
2485	−17.0	−63.1	−56.8	−48.6	−72.8
2487		−49.8	−49.3	−19.2	−35.5
2696		−34.5	−33.3	−14.3	−27.0

Appendix I (Continued)

Number Sp.	Hα	Hβ	Hγ	Hδ	Hε
2806		7.9	−1.2	2.7	2.5
2807	−48.3	−26.0	−12.6	−19.0	−24.6
2861		(105.3)	13.8	−15.4	−32.9
2862		(106.6)	8.8	−22.2	−54.6
2874	(138.3)	29.7	9.1	1.8	−16.9
2875		−22.1	6.3	3.5	−1.7
3040		−24.5	−35.6	−20.9	−49.8
3041		64.1	−30.1	0.9	−22.6
3042		4.9	−7.1	4.1	−34.8
3043		−18.5	−51.6	−35.0	20.5
3049		−20.5	−48.1	17.5	−23.8
3050		−30.3	−6.0	−14.3	−21.0
3051		33.8	83.5	−43.0	−17.2
3052	73.0	−39.9	−3.2	7.3	−22.1
A 1451	−23.9	−35.1	−23.1	−55.0	−12.1
A 1452		13.2	−16.3	−26.2	−31.9
A 1453		−13.1	−56.4	53.7	−15.2
A 1461	−67.7	(149.4)	−3.1	−16.8	24.3
A 1462	−5.2	45.6	−2.5	−5.2	9.9
A 1463		66.1	27.2	−36.2	−41.0
ZCM 326		6.8	−32.8	−8.3	−40.0
ZCM 334	(234.5)		20.5		
ZCM 343		(118.2)	−29.5	17.3	(140.4)
ZCM 344		18.6	−27.2	58.1	
ZCM 536		−7.9	−30.5	−49.7	−63.2
ZCM 537		37.5	−43.6	−34.2	−78.4
ZCM 538		27.6	−53.3	−52.6	−69.6
ZCM 568		54.9	−25.4	−11.1	
ZCM 733		34.4	−26.1	4.0	−48.6
ZCM 734		20.8	−21.5	−38.0	−42.9
ZCM 735	107.6	22.1	6.9	−10.8	−4.7
ZCM 741	94.6	34.6	−9.3	−5.5	−51.3
ZCM 742		29.5	−11.5	−0.2	−33.2

Number Sp.	Hα			Hβ	Hγ	Hδ	Hε
	emiss.$_R$	absorp.	emiss.$_V$				
ZCM 839				114.8	23.0	−21.6	
ZCM 840		−59.5	−285.7	117.6	30.3	50.7	−60.1
ZCM 856				−67.4	−114.7	−82.0	−88.8
ZCM 857	118.9	−127.8	−341.3	−42.2	−107.6	−92.7	−124.3
A 2046		−46.1		14.9	−30.3	6.8	−38.2
A 2047		−35.7		−9.3	−13.6	−12.7	−52.4
ZCM 858	68.3	−200.0	−394.9	−74.2	−106.2	−78.5	−132.9
ZCM 859				−82.7	−111.0	−71.6	−135.0
ZCM 860				−59.1	−70.0	−89.4	−109.1
ZCM 861		−152.3	(−426.1)	−21.6	−64.2	−29.3	
ZCM 862	106.7	−124.7	−322.6				

Appendix I (*Continued*)

Number Sp.	Hα emiss.$_R$	absorp.	emiss.$_V$	Hβ	Hγ	Hδ	Hε
ZCM 868	239.7	−45.2	−286.6	−35.7	−38.9	−64.4	−52.1
ZCM 871	163.7	−12.2	−213.2	−80.2	−80.5	−68.5	−96.5
ZCM 873	242.3	57.5	−205.9	−24.1	−60.9	−63.8	−96.6
ZCM 874				−71.0	−98.6	−90.8	−138.8
ZCM 875				−115.8	−92.0	−99.4	−109.6
ZCM 877	(733.9)	126.8	−21.9	−86.6	−103.7	−62.5	−97.7
ZCM 879	194.2	−13.8	−274.0	−138.5	−119.7	−120.6	−133.6
ZCM 880	117.8	−35.3	−253.5	−53.7	−49.1	−77.9	−102.2
ZCM 881	201.7	3.4	−237.2	−26.5	−31.3	−53.3	−94.8
ZCM 884	125.9	−27.2	−229.3	−33.3	−43.8	−44.3	−63.3
ZCM 885		−88.8	−326.1	−73.0	−75.0	−28.8	−63.2
ZCM 886	273.5	−53.7	−334.0	−20.2	−37.3	−41.8	−52.2
ZCM 888	165.0	−71.6	−339.7	−54.1	−42.8	−47.4	−87.2
ZCM 891	181.8	−39.5	−316.3	−54.7	−59.3	−59.5	−80.3
ZCM 892	198.0	−32.8	−286.1	−23.9	−55.1	−44.4	−108.0
ZCM 915	75.9	−73.1	−340.6	−41.3	−55.7	−34.3	−22.8
ZCM 916	164.7	−60.2	−258.2	−12.7	−85.2	−55.4	−98.1
ZCM 917	167.8	−83.1	−284.1	−72.8	−80.4	−92.5	−49.0

APPENDIX II

Radial velocities of helium lines: missing values are due to the limited spectral range of the plate or to the visibility of the lines; from the spectra ZCM 840 (23 July, 1975) He I 14, He I 48 and He I 51 are blended with metallic lines

Number Sp.	He I 11	He I 14	He I 51	He I 18
2461				−12.8
2470		−22.1	−52.5	−33.3
2485		−49.2		−105.5
2487		−50.8		−25.9
2696				2.8
2807	40.6	12.5	−66.7	−46.5
2874		1.0	−1.7	15.2
3040				−12.4
3042		(−99.2)	−79.2	−37.2
3043		50.1		−17.2
3052				−35.9
A 1451				−47.3
A 1461		−5.3	−30.5	−6.1
A 1462		−6.7	−81.1	−43.9
A 1463		−37.3	−48.5	9.4
ZCM 326		−38.8		−96.5
343				(−136.8)
344				(−104.2)
536		−19.3	−52.7	−57.6
537		−18.4	−109.8	−110.6
538				−88.2

Appendix II (*Continued*)

Number Sp.	He I 11	He I 14	He I 51	He I 18
ZCM 568		−53.8	44.5	
733		−49.7	11.0	−76.0
734		−6.0		−23.7
735		−47.8	13.1	13.5
741				13.6
742				19.0
840				−73.8
858	(−132.5)			−110.1
A 2046				3.4
A 2047				−2.6
ZCM 860				−126.4
862	−134.4			
868	−57.2			−118.0
871	−7.9			
873	−63.9			−48.5
875				−195.6
877	−49.9			−136.8
880	−5.7			−98.1
881	−4.4			−29.6
884	−52.3			−86.6
885	−105.9			
886	−95.9			−147.6
888	−28.9			
891	25.5			
892	(−163.8)			−140.2
915	−49.4			

Number Sp.	He I 48	He I 53	He I 55	He I 58	He I 22
2485	−2.8	−80.1			
2807	10.2	41.3	5.1	−58.1	−42.1
3040					−19.9
A 1451	−76.7		57.5		−48.5
A 1452					−6.1
A 1461			43.4		
A 1463	(−37.1)	−17.6	−50.0		17.2
ZCM 537			−75.9		
538		−52.3			
568		55.7			
733			−26.9		
742					−28.0
840		94.9	14.7		
A 2046			−14.6		
ZCM 880		−35.5			
881			−65.5		−31.3
892			−53.8		
915		64.5			

APPENDIX III

Radial velocities of metal lines: missing values are due to the spectral range or to the visibility of the lines

Number Sp.	Na I 1	Mg II 16	Mg II 4	Si II 3	Ca II 1
2470			−32.8		
2485					−19.9
2487			−36.8		
2696					14.4
2807	94.0		−2.0	27.1	−50.8
2874			33.2		
3042			6.9		
ZCM 536			−41.9		
537			26.6		
568			−43.6		
733			−2.0		
734			−5.9		−8.2
735					−3.2
741					−32.0
742			40.8		−10.8
840	−98.4		58.6		
857		−151.9			
A 2046					−7.5
A 2047					−17.8
ZCM 858	−226.2	−140.8			−23.8
861		−78.5			
862	−345.9				
868	4.0	−64.5	14.3		
871	−160.0	4.7	−62.2	−42.0	−46.3
873	58.2	59.7	−69.4		−61.8
874			−62.1		
875			−78.9		−22.4
877	33.1	−74.8	−13.7		+11.5
879		−61.9			
880	74.2	1.2	−36.7		−56.2
881	67.1	72.6	−56.7		17.2
884	99.9	2.8	−34.4		−52.9
885	−8.4	−73.1	−25.0		−71.3
886	10.0				−35.2
888	48.2	3.1	2.2		−23.8
891	63.4	−16.0	−22.4		−7.6
892	−112.9	86.1	13.2		−30.1
915	148.0				
917		−16.0			

Appendix III (*Continued*)

Number Sp.	C II 6	Fe II 210	Fe II 40	Fe II 200	Fe II 49
2807	63.0				
ZCM 857			6.4		
858			−35.3		
861		−17.4			
868		7.8	20.0	−25.3	
871			84.8		
873			134.6		
877		6.9	38.0		
879			−37.7		
880		30.4	50.1		
881			180.5	4.0	
884		105.9	171.6		−38.9
885		11.0	−69.5		
888			19.0		
891		76.1			
917		−11.5	−22.7		

Number Sp.	Fe II 42		Fe II 38		
	$\lambda\lambda$ 5169.03	$\lambda\lambda$ 5018.43	$\lambda\lambda$ 4583.83	$\lambda\lambda$ 4549.47	$\lambda\lambda$ 4522.63
ZCM 741		−25.4			
840			17.8	84.2	57.9
868	2.3				
871			−44.9		
873		(−58.7)			
880		(−58.2)	−34.1		
884	−30.9	−62.3	−21.9		
885	−86.0				
886	20.2	−30.9			
888	−1.1	−71.3			
892	−36.2				

	Fe II 27		Fe II 37		
	$\lambda\lambda$ 4351.76	$\lambda\lambda$ 4233.17	$\lambda\lambda$4555.59	$\lambda\lambda$ 4515.34	$\lambda\lambda$ 4491.40
ZCM 840	−8.9	25.7	44.6	−37.2	−18.8
881		7.2			
884		10.3			
891					−56.2
892		−74.9			−27.4

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