SPECTROGRAPHIC OBSERVATIONS OF THE SUSPECTED DELTA SCUTI VARIABLE BETA ARI

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Abstract. Three sets of spectra (in all 85 spectra) of the well-known standard and high eccentricity spectroscopic binary star Beta Ari were taken with the Boller and Chivens grating spectrograph (29 and 35 Å mm^{-1}) applied to the 137 cm reflector of the Merate Astronomical Observatory. These sets were taken *during* the periastron passage of 14–15 November 1976, *after* the periastron passage of 2–3 October 1977 and before the apastron passage of 23 November 1977.

The analysis of the radial velocities RV and equivalent widths W_λ of hydrogen and metal lines show periodic variations similar to those of some classical Delta Scuti stars. The variations of the asymmetries of the profiles of H and Ca II K lines, linked to the variations of the RV seem to recall the Schuster effect observed in classical Cepheids.

A periastron effect appears from: (a) increased amplitudes of the RV curves, (b) remarkable variations of the averaged W_λ curves, (c) strong positive asymmetry (blue wing larger than red wing) in the Hγ and Ca II K lines.

A faint 'bump' in RV and W_λ curves of Ca II K line is singled out and could be in agreement with some theoretical forecasts of Aleshin (1964).

1. Introduction

Beta Ari is a well-known single-line spectroscopic binary (Vogel, 1903; Ludendorff, 1907; Gorza and Heard, 1971) with the highest eccentricity (Petrie, 1938). The general characteristics of this star are: DM + 20°306, HD 11636, GC 2309, HR 553, Wilson Catalogue No. 1058, Parallaxes Catalogue No. 394, $\alpha_{1900} = 01^h49^m07^s$, $\delta_{1900} = +20°19'$, $m_v = 2.65$, $B - V = 0.13$, S.T. = A5V, Am (Cowley *et al.*, 1969), $v \sin i = 70$–$80\,km\,s^{-1}$ (Slettebak, 1955; Abt, 1975).

Gorza and Heard (1971) give also: $T = 2440208.398 \pm 0.033$, $P = 106^d.9973 \pm \pm 0.0012$, $e = 0.892 \pm 0.003$, $\omega = 20^\circ.0 \pm 1^\circ.3$, $K = 37.1 \pm 0.9\,km\ s^{-1}$, $\gamma = -4.0 \pm \pm 0.4\,km\,s^{-1}$, $a \sin i = (24.3 \pm 0.1) \times 10^6\,km$, $f(M) = (0.055 \pm 0.004)M_\odot$.

According to Dommanget (1967) the high eccentricity of this system could produce a 'periastron effect' (mass transfer, increase of reflection) when the stars are at minimum distance ($\lesssim 50R_1$).

Photometric observations of Hogata (1973), Lovell and Hall (1971), have revealed no variation higher than 0.02–0.01 magnitude, nevertheless some intrinsic, irregular variability could hide a periastron effect.

Beta Ari has been adopted as photometric 'standard star' also recently (Van Gen-

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deren, 1971) and its spectral energy distribution carefully determined (Breger, 1976; Kharitonov and Glushneva, 1978). Yet Guthnick and Prager (1918) suspected its variability; and Kukarkin *et al.* (1951) included it in the catalogue of suspected variables; while Frolov (1970) included this star in a list of suspected Delta-Scuti variables. Photometric observations by Weiss (1978) exhibit faint magnitude variations ($\Delta m \leq 0.01$).

The variability of Beta Ari could be complicated by periastron effect and tidal effects between the companions at periastron passage. As it is known, tidal modulations of pulsations of Beta CMa and Delta-Scuti stars, belonging to high eccentricity binary spectroscopic systems (16 Lac, Beta Cep) have been found and carefully studied by Fitch (1969): whereas no correlation between the intrinsic pulsation and the orbital motion of 14 Aur has been found by Morguleff *et al.* (1976).

From 1973 to 1977 several observations of our spectrographic survey of the list of Frolov (Antonello *et al.*, 1978) were dedicated to Beta Ari.

2. Observations and Reductions

The spectra of the present study were taken with the Boller and Chivens grating spectograph (dispersion 29 and 35 Å mm^{-1}) applied on the 137 cm reflector of the Merate Observatory and reduced with the method reported in our previous paper (Antonello *et al.*, 1978). All computations were performed at the PDP/11 computer of the Merate Observatory.

Three sets of spectra were obtained: the first, consists of 29 spectra (BCL, 29 Å mm^{-1}) covering five hours *during* the periastron passage (14–15 November 1976), with exposure of two minutes (Kodak plates 098-2); the second, consists of 28 spectra (BCC, 35 Å mm^{-1}) covering five hours, a day *after* the periastron passage (2–3 October 1977), with exposures of seven minutes (Kodak plates IIaO); the third consisting of 28 spectra covering six hours half a day *before* the apastron passage (BCC, 23 November 1977).

The spectra show intense Balmer lines and many metallic lines in the range Hβ–Ca II K. The list of the spectral lines identified by means of an Fe–A comparison arc are reported in Table I.

TABLE I
Absorption lines identified in spectra of Beta Ari

N	Wavelength (Å)	Element and multiplet	
1	3889.051	H_8	x
2	3914.312	⟨Fe I 567, Ti I 15⟩	
3	3933.664	Ca II K	x
4	3970.074	Hε	x
5	4005.254	Fe I 43	x
6	4025.136	Ti II 11	x
7	4045.815	Fe I 43	x
8	4063.605	Fe I 43	x

Table I (continued)

N	Wavelength (Å)	Element and multiplet	
9	4071.749	Fe I 43	x
10	4077.713	⟨Sr II 1⟩	x
11	4101.737	Hδ	x
12	4127.708	⟨Fe I 558, 727, Fe I 357⟩	
13	4132.067	Fe I 43	
14	4143.878	Fe I 43	
15	4178.859	Fe II 28	
16	4184.155	⟨Fe I, Ti II 21⟩	
17	4187.430	Fe I 152	
18	4191.437	Fe I 152	x
19	4202.040	Fe I 42	x
20	4205.544	Fe I 689	
21	4210.369	⟨Fe I 483, Fe I 152⟩	
22	4215.539	⟨Sr II 1⟩	
23	4227.090	⟨Ca I 2, Fe I 693⟩	x
24	4233.391	⟨Fe I 152, Fe II 27⟩	
25	4250.463	⟨Fe I 42, Fe I 152⟩	
26	4260.486	Fe I 152	
27	4271.774	Fe I 42	x
28	4282.713	⟨Ca I 5, Fe I 71⟩	
29	4290.226	Ti II 41	x
30	4303.177	Fe II 27	
31	4307.912	Fe I 42	x
32	4312.875	Ti II 41	
33	4320.958	Ti II 41	
34	4325.775	Fe I 42	
35	4340.468	Hγ	x
36	4351.767	Cr I 22	
37	4374.649	⟨Ti II 93, Sc II 14⟩	
38	4383.937	⟨Fe II 32, Fe I 41⟩	x
39	4394.554	⟨Ti II 19, Ti II 51⟩	
40	4400.088	⟨Sc II 14, Ti II 51⟩	
41	4404.761	Fe I 41	x
42	4415.135	Fe I 41	
43	4418.033	⟨Ti II 51, Ti II 40⟩	
44	4443.812	Ti II 19	
45	4476.061	⟨Fe I 830, Fe I 350⟩	
46	4481.228	⟨Mg II 4⟩	x
47	4501.278	Ti II 31	x
48	4508.289	Fe II 38	
49	4515.343	Fe II 38	
50	4522.723	⟨Ti I 42, Fe II 38⟩	
51	4534. 071	⟨Fe II 37, Ti II 50⟩	
52	4541.523	Fe II 38	
53	4549.544	⟨Ti II 82, Fe II 38⟩	x
54	4571.982	Ti II 82	
55	4576.339	Fe II 38	
56	4583.336	⟨Fe II 38, Fe II 57⟩	x
57	4588.204	Cr II 44	
58	4731.473	Fe II 43	
59	4861.332	Hβ	x
60	6562.817	Hα	

* The 'x' indicates the lines used for *RV* or W_λ determinations.

3. Results

The radial velocities RV and the equivalent widths W_λ of the spectral lines selected for the present study are reported in Tables II–IV for the hydrogen lines, and in Tables V–VII for the metallic lines. The average errors of measurements are $\pm$ 3 km s^{-1} for the RV and $\sim$ $\pm$ 10% for the W_λ.

In Figures 1–3 the averaged values of RV and the averaged *normalized* values of W_λ of the hydrogen lines, vs the heliocentric Julian Days are plotted. In Figures 4–6 are plotted the same averages for the metallic lines. The dotted lines reported in the RV figures are the orbital RV of the system Beta Ari, at the same phases, given by Gorza and Heard (1971).

TABLE II

RV (km s^{-1}) and W_λ (Å) of hydrogen lines during the periastron passage of 1976 (instant of passage: 24434097.3251 Hel. J.D.)

Hel. J.D. 24434090+	Hε		Hδ		Hγ	
	RV	W_λ	RV	W_λ	RV	W_λ
7.352	+ 6.6	19.37	+44.6	18.16	+50.6	17.81
7.355	+21.8	18.06	+98.7	17.82	+85.1	15.72
7.359	−41.7	20.58	+32.9	21.29	+14.6	15.25
7.375	+32.3	21.25	+61.6	23.47	+65.5	17.70
7.383	+15.4	20.32	+43.3	18.33	+39.5	16.43
7.387	+23.3	19.35	+63.4	19.66	+44.8	19.98
7.391	−7.0	21.58	+38.6	21.28	+22.0	16.53
7.395	+44.1	18.92	–	17.09	+54.6	16.05
7.398	−10.0	16.45	+47.1	18.29	+28.5	15.82
7.414	+37.7	19.52	+90.9	20.59	+60.2	16.62
7.418	−18.1	15.36	+58.4	17.37	+60.7	12.94
7.422	−23.7	18.74	–	21.40	+45.5	17.54
7.426	−27.2	19.12	+57.9	20.30	+72.9	19.49
7.430	−34.2	19.52	+55.9	18.31	+28.7	15.91
7.434	+34.9	19.30	+74.9	21.47	+96.4	19.15
7.449	+18.4	18.38	+52.7	19.26	+68.5	15.82
7.453	−30.5	18.68	–	17.77	+43.0	14.68
7.457	+23.7	20.41	+70.3	21.70	+55.7	16.52
7.488	−42.2	17.26	+20.2	19.42	+10.1	16.37
7.496	+45.3	18.66	+ 7.4	22.11	+36.2	20.02
7.504	+ 6.8	19.37	+59.1	22.81	+58.6	18.44
7.508	− 4.0	18.70	+52.4	22.44	+32.1	19.88
7.512	− 3.0	21.30	+31.0	25.39	− 2.1	21.15
7.523	−13.7	20.88	+32.7	20.74	+ 9.2	18.47
7.527	−19.2	17.46	+41.6	19.72	+ 7.8	19.95
7.531	−16.3	18.33	+36.7	20.11	+ 3.6	18.27
7.535	−29.0	21.84	+38.8	20.42	+48.1	19.03
7.539	−12.6	18.27	+57.1	22.62	+27.0	19.92
7.544	−22.3	20.48	+23.8	22.86	+24.4	15.99

TABLE III

RV (km s^{-1}) and W_λ (Å) of hydrogen lines near the periastron passage of 1977 (instant of passage: 2443418.3170 Hel. J.D.)

Hel. J.D. 2443410+	Hε		Hδ		Hγ		Hβ	
	RV	W_λ	RV	W_λ	RV	W_λ	RV	W_λ
9.414	−18.6	15.28	− 7.2	17.89	− 4.2	15.88	+34.9	16.56
9.422	−64.4	13.42	−19.6	18.67	− 7.5	17.69	−50.3	–
9.430	–	14.07	− 5.1	19.81	− 9.3	18.11	16.0	12.45
9.437	−40.0	16.85	+ 9.1	18.21	− 4.8	16.72	+ 2.2	16.45
9.445	−33.6	17.84	−23.9	18.91	−37.4	18.00	−80.4	14.96
9.449	−47.2	17.11	−22.6	19.75	− 1.6	17.66	−99.9	16.41
9.457	−86.0	17.60	−10.1	17.63	−30.8	16.21	−38.1	13.36
9.469	−23.2	18.06	− 1.2	18.40	−21.6	17.04	+ 9.2	15.12
9.473	−24.6	19.51	+12.3	19.67	− 5.7	14.67	−42.7	13.31
9.480	−15.0	18.52	− 0.1	14.05	− 3.5	12.14	−10.4	14.85
9.496	−24.5	17.53	+19.5	16.34	− 9.0	13.81	−13.6	16.38
9.504	+22.7	20.17	+ 2.5	19.64	−16.2	14.32	− 2.2	15.85
9.512	−28.4	17.86	− 3.6	14.64	− 5.7	14.30	+ 2.4	12.09
9.527	−30.5	19.50	+31.4	20.41	− 4.6	18.19	−67.2	18.78
9.535	+ 2.8	15.82	00.0	19.41	−10.7	17.17	− 1.9	13.20
9.539	+15.1	17.78	−14.4	18.98	−29.0	16.77	–	16.83
9.551	−33.0	18.63	−12.4	17.36	−27.8	15.77	− 4.3	14.34
9.559	−28.0	16.05	−13.2	21.84	−15.0	16.63	−13.2	16.19
9.566	−40.8	17.51	+19.7	18.35	−16.7	18.67	−46.4	14.05
9.578	−81.8	17.38	+31.0	20.06	−14.5	18.99	−48.2	18.90
9.582	−49.3	19.98	−21.3	19.48	+11.1	16.98	−13.3	13.94
9.594	+22.8	18.00	+23.1	18.73	+ 6.7	17.14	+ 3.5	15.41
9.602	−48.2	17.83	+ 9.2	18.95	+ 0.2	16.71	−20.0	21.94
9.609	−45.3	15.00	− 2.3	17.06	−20.4	18.54	+ 8.6	16.65
9.617	−59.9	16.86	−32.1	17.76	− 7.8	13.68	−33.4	14.81
9.625	−70.3	17.10	+22.7	19.81	−12.7	16.44	−42.1	16.60
9.633	−47.9	18.04	−12.3	17.76	− 3.9	14.88	+ 3.9	12.63
9.641	− 9.6	15.78	−20.1	18.82	− 2.4	18.3	− 8.7	17.12

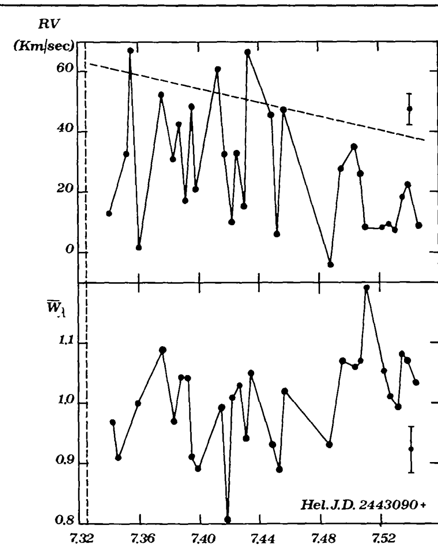

Fig. 1. Averaged RV and averaged *normalized* W_λ vs heliocentric Julian Days, for the hydrogen lines at the periastron 1976. In figure is reported the instant of periastron passage (vertical dotted line) and the orbital RV of the system (transversal dotted line). The averaged RV error bar and the averaged *normalized* W_λ error bar are reported.

TABLE IV

RV (km s^{-1}) and W_γ (Å) of hydrogen lines near the apastron passage of 1977 (instant of passage: 2443471.8157 Hel. J.D.)

Hel. J.D. 2443470+	Hε		Hδ		Hγ		Hβ	
	RV	W_λ	RV	W_λ	RV	W_λ	RV	W_λ
1.246	− 91.4	14.42	−61.3	16.51	+ 2.9	16.06	−46.3	–
1.254	−104.6	16.14	−51.6	19.05	−39.6	14.88	−59.1	–
1.262	+ 3.5	12.61	+18.3	16.55	−19.6	14.12	−41.5	–
1.270	− 50.1	16.23	− 7.3	15.85	−31.7	13.72	−31.1	17.00
1.277	− 98.5	16.63	−61.8	17.07	−75.5	18.26	–	–
1.285	− 94.9	–	+12.9	17.11	−65.9	13.85	−76.4	14.85
1.293	− 73.4	15.19	− 8.7	17.61	−26.0	19.91	−75.3	14.33
1.301	− 19.5	17.67	− 4.7	17.31	− 2.9	17.75	−63.9	18.28
1.309	− 66.7	14.04	− 2.0	18.23	−44.0	17.58	+11.4	12.12
1.316	− 98.3	14.36	− 2.8	16.25	−23.9	16.44	−65.5	15.34
1.324	–	15.65	−10.1	17.36	−35.4	16.16	−21.4	12.91
1.328	− 37.1	17.79	− 0.9	16.30	−48.2	15.23	+10.9	15.20
1.340	− 44.0	16.39	−24.9	20.23	−25.5	15.47	− 0.3	14.77
1.344	+ 30.8	15.38	+ 2.3	17.28	−93.8	16.21	−19.4	13.16
1.352	–	16.62	+18.0	16.21	−41.7	16.09	−58.6	17.44
1.359	− 17.2	17.42	−30.1	15.85	− 7.1	15.34	−50.3	13.38
1.367	− 73.6	16.33	+ 5.5	17.84	−50.7	16.87	+15.8	14.19
1.375	–	16.72	−31.0	20.57	−64.8	13.21	−18.4	11.46
1.385	− 5.8	15.96	−32.3	16.42	−18.1	16.30	−21.3	11.09
1.391	–	15.56	+30.0	17.89	−54.9	16.38	−25.6	14.67
1.398	–	16.30	+25.1	18.71	−58.8	17.14	+10.2	16.96
1.410	− 51.1	13.87	−13.9	16.64	−26.0	19.15	+10.5	13.86
1.418	− 51.0	14.71	−21.0	20.95	− 1.6	14.90	+10.3	13.35
1.426	− 51.9	15.66	+13.5	21.04	+ 1.5	16.79	−18.1	16.99
1.434	+ 25.6	15.18	−11.7	18.79	−29.1	16.33	−15.3	15.82
1.441	− 65.3	17.15	+ 8.7	16.85	−40.7	16.09	−22.1	15.04
1.449	− 59.4	15.20	−62.8	17.20	−37.9	15.59	−33.0	13.51
1.457	− 72.3	14.52	− 0.3	14.77	−35.1	18.14	−17.6	14.89
1.465	–	17.13	−12.0	17.83	−44.3	15.40	+ 0.8	13.57
1.473	− 47.6	17.38	−22.8	16.67	−18.6	18.09	−11.6	13.10

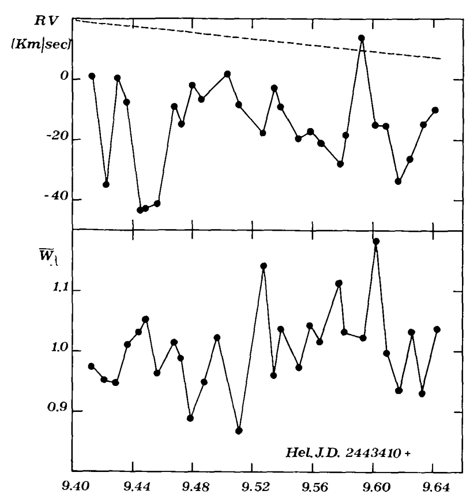

Fig. 2. Averaged RV and averaged *normalized* W_λ vs heliocentric Julian Days, for the hydrogen lines at the periastron 1977 (symbols as in Figure 1).

TABLE V (a)

RV (km s^{-1}) of metallic lines during the periastron passage of 1976

Hel. J. D. 24434090+	λ 3933 (3)	λ 4045 (7)	λ 4063 (8)	λ 4071 (9)	λ 4077 (10)	λ 4290 (29)	λ 4481 (46)	λ 4549 (53)
7.352	+59.8	+51.5	+34.2	+30.3	+31.8	+39.2	+60.4	+66.5
7.355	+90.4	+71.7	+70.9	–	+66.7	–	+82.1	–
7.359	+27.5	+35.4	– 2.1	+57.1	+33.4	–27.1	+49.7	–
7.375	+91.1	+88.6	+77.2	+74.3	+64.4	+57.6	+81.7	+75.4
7.383	+59.4	+27.5	+38.8	+27.6	+50.8	+ 1.2	+61.3	+42.0
7.387	+77.2	+61.8	+66.8	+73.7	+43.7	+ 3.8	+69.3	–
7.391	+45.3	+35.6	–19.5	–	+35.3	–14.9	+45.8	–
7.395	–	+88.7	+73.6	–	+69.8	–	–	–
7.398	+42.1	+52.6	+10.5	– 2.1	+21.1	+23.2	+47.2	+54.7
7.414	+90.3	+62.1	+51.8	–	+87.5	–	+86.7	–
7.418	+59.4	+47.6	+28.2	+35.3	+43.5	+ 5.7	+63.5	–
7.422	+55.0	+62.9	+30.6	+61.5	–	–	+64.3	+60.1
7.426	+43.5	+47.8	+ 8.9	+13.2	+33.2	+30.2	+54.0	+48.9
7.430	+23.0	+26.2	+32.3	+34.0	+32.9	+38.9	+44.6	–
7.434	–	+73.1	+66.6	+89.6	+71.9	+25.2	–	–
7.449	+97.2	+71.5	+67.7	–	+72.7	–	+78.8	+82.0
7.453	+41.7	+30.1	– 2.5	+40.9	+31.4	+11.8	+44.4	+35.0
7.457	+82.6	+67.6	+59.3	+59.7	+49.9	+40.9	+82.3	–
7.488	+50.2	+38.5	00.0	+46.6	+ 5.2	+17.5	+33.8	–
7.496	+64.6	+34.9	+ 9.1	+42.5	+46.2	+27.9	+44.1	+58.9
7.504	+86.0	+65.0	+48.4	+74.5	+58.5	–	+79.4	–
7.508	+50.8	+46.0	+34.7	–	– 9.6	+35.5	+43.7	–
7.512	+36.4	+29.7	– 5.3	+44.6	+36.4	– 8.7	+41.5	–
7.523	+47.4	+37.6	– 0.2	+37.8	+22.1	–	+41.8	–
7.527	+50.8	+19.6	+31.8	–	+12.0	+25.2	+60.6	–
7.531	+40.0	+35.6	– 3.6	+29.3	+17.3	+11.5	+26.5	–
7.535	+57.2	+57.0	+14.8	–	+16.3	–26.2	+52.6	–
7.539	+84.8	+36.1	+45.0	+54.4	–	+27.8	+53.9	–
7.544	+37.6	+21.1	+ 1.2	–	+20.9	+12.9	+24.9	–

The numbers in parentheses refer to the Table I.

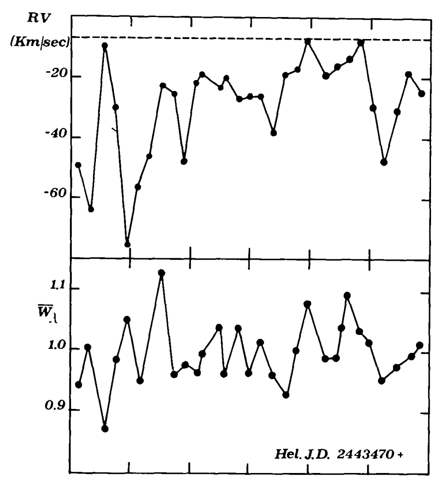

Fig. 3. Averaged RV and averaged *normalized* W_λ vs heliocentric Julian Days, for the hydrogen lines at the apastron 1977 (symbols as in Figure 1).

TABLE V (b)

W_λ (Å) of metallic lines during the periastron passage of 1976

Hel. J. D. 24434090+	λ3933 (3)	λ4045 (7)	λ4063 (8)	λ4071 (9)	λ4077 (10)	λ4290 (29)	λ4481 (46)	λ4549 (53)
7.352	3.862	0.367	–	–	0.572	0.448	0.690	0.423
7.355	3.093	0.259	0.303	0.350	0.636	0.355	0.814	0.573
7.359	3.864	0.530	0.324	0.348	0.943	0.298	0.905	0.535
7.375	4.063	0.244	0.435	0.510	1.100	0.471	0.830	0.497
7.383	3.895	0.371	0.206	–	0.827	0.424	0.702	0.485
7.387	3.930	0.366	–	0.291	0.638	0.324	0.813	0.430
7.391	4.491	0.294	–	–	1.024	0.316	0.677	0.436
7.395	3.719	0.418	0.204	0.253	0.527	0.304	0.618	0.423
7.398	3.489	0.346	–	–	0.792	0.323	0.617	0.548
7.414	3.520	0.420	0.238	–	0.979	0.287	0.677	0.543
7.418	3.571	0.520	0.378	0.411	0.567	0.173	0.664	0.487
7.422	3.589	0.466	0.449	0.475	0.825	0.421	0.792	0.494
7.426	3.769	0.262	0.187	0.322	0.738	0.526	0.652	0.540
7.430	3.961	0.414	–	0.335	0.778	0.333	0.796	0.515
7.434	3.626	0.413	0.370	–	0.964	0.274	–	0.652
7.449	3.679	0.289	0.389	0.269	0.513	0.326	0.715	0.592
7.453	3.979	0.359	–	–	0.639	0.223	0.714	0.617
7.457	4.004	0.352	0.341	0.333	0.930	0.357	0.771	0.466
7.488	3.518	0.311	0.303	0.298	0.705	–	0.779	0.493
7.496	3.367	0.391	0.314	0.423	1.138	0.531	0.939	0.701
7.504	3.728	0.284	0.333	0.286	0.656	0.254	0.728	–
7.508	3.753	0.343	0.293	0.320	0.616	0.418	0.828	–
7.512	3.645	0.482	0.360	0.351	1.106	0.427	0.746	–
7.523	4.267	0.189	0.309	0.286	0.953	0.284	0.746	–
7.527	3.475	0.261	0.381	0.393	0.944	–	0.815	–
7.531	3.493	0.367	0.445	0.266	0.939	0.290	0.798	–
7.535	3.845	0.481	0.269	0.375	1.227	0.376	0.815	–
7.539	3.121	0.320	0.549	0.557	1.007	0.516	0.756	–
7.544	3.616	0.286	0.271	0.450	0.931	0.442	0.692	–

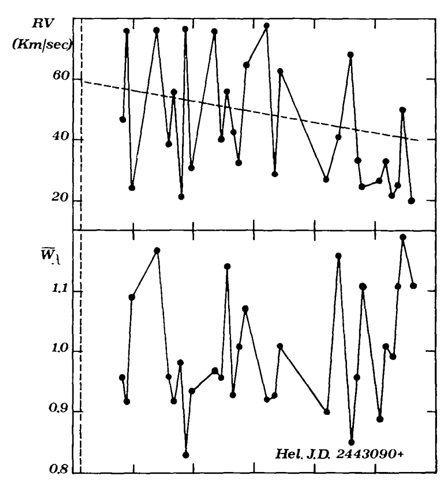

Fig. 4. Averaged RV and averaged *normalized* W_λ vs heliocentric Julian Days, for the metal lines at the periastron 1976 (symbols as in Figure 1).

TABLE VI (a)

RV (km s^{-1}) of metallic lines near the periastron passage of 1977

Hel. J.D. 2443410+	λ3933 (3)	λ4045 (7)	λ4063 (8)	λ4071 (9)	λ4077 (10)	λ4290 (29)	λ4481 (46)	λ4549 (53)
9.414	+29.6	−19.8	−27.4	−22.5	−39.2	− 9.9	+11.3	− 2.9
9.422	− 7.6	−41.8	−44.0	−	−17.7	−81.0	+ 3.1	+ 3.1
9.430	+51.2	+17.9	−62.3	+ 7.8	−	−17.1	+10.6	+14.8
9.437	+18.0	−10.7	−61.3	−	−17.3	−11.1	+10.5	+ 0.9
9.445	+ 1.4	−17.0	−25.4	+28.3	−17.5	− 5.4	+16.6	+ 9.2
9.449	+20.3	+25.5	−15.1	+ 5.9	+18.2	−14.4	+ 6.4	+14.1
9.457	+ 5.7	−21.8	−42.1	−29.9	+ 0.8	−26.8	− 6.7	− 5.6
9.469	−11.8	−36.3	−34.5	−12.5	− 2.2	−25.0	− 7.4	+ 0.1
9.473	+24.1	−17.0	−25.0	−27.9	−16.4	−33.1	+ 2.1	− 3.8
9.480	+30.6	− 1.1	− 6.3	−20.2	+ 3.0	−41.0	+ 7.6	− 3.4
9.488	+32.7	+16.3	+18.7	− 0.6	+ 0.9	−14.5	+17.9	+14.8
9.496	+15.5	−30.7	−25.8	−33.1	+14.0	−19.4	+ 6.7	+ 8.2
9.512	+16.0	+ 1.6	−21.3	+ 6.4	−15.6	−27.7	+ 9.4	+ 5.8
9.527	+19.0	−	−	− 6.4	+ 5.0	−17.4	+ 9.0	+ 9.3
9.535	+ 3.9	− 5.5	−15.7	− 1.2	−20.1	− 3.4	+ 4.5	− 2.3
9.539	+11.7	− 5.8	−12.8	+ 5.9	+ 6.5	− 8.7	+14.0	+11.8
9.551	+ 0.6	− 6.7	−23.8	+ 2.9	− 4.0	−42.3	+ 3.5	−10.6
9.559	+22.8	−16.7	−46.7	−	+ 9.2	−29.5	+ 6.0	− 8.4
9.566	+25.0	−21.6	−50.1	−	−19.8	− 3.6	+ 8.6	− 6.0
9.578	+24.0	−14.8	−14.7	− 5.0	+ 6.1	−17.5	+ 6.3	− 6.2
9.582	+17.8	− 9.7	− 8.7	− 6.0	−28.0	−25.2	+ 7.9	− 2.3
9.594	+15.8	+14.9	− 7.1	−	+ 1.3	−30.5	+ 0.6	+ 2.7
9.602	+24.7	−19.4	− 8.5	− 4.7	− 9.2	−15.8	+ 8.8	− 8.8
9.609	+30.6	− 5.8	−41.4	− 3.8	−20.3	−14.6	+ 0.8	+ 4.8
9.617	− 6.5	−36.7	−12.1	+ 6.1	−21.1	−61.4	− 9.1	−14.9
9.625	−	− 8.2	+ 8.1	− 9.8	+11.4	−28.9	+ 1.8	+15.6
9.633	+25.9	−14.1	−11.1	+19.6	+ 3.0	−31.4	+ 8.7	+ 3.7
9.641	+ 9.6	−	+ 7.1	−	−41.9	−10.1	+ 3.0	+10.5

The numbers in parentheses refer to the Table I.

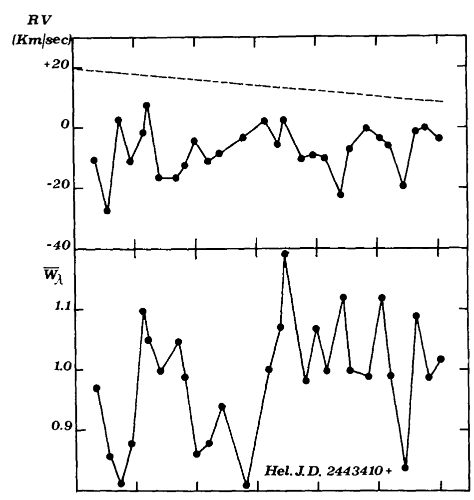

Fig. 5. Averaged RV and averaged *normalized* W_λ vs heliocentric Julian Days, for the metal lines at the periastron 1977 (symbols as in Figure 1).

TABLE VI
W_λ (Å) of metallic lines near the periastron of 1977

Hel. J.D. 2443410+	λ3933 (3)	λ4045 (7)	λ4063 (8)	λ4071 (9)	λ4077 (10)	λ4290 (29)	λ4481 (46)	λ4549 (53)
9.414	2.232	0.396	0.338	0.295	0.765	0.572	0.806	0.675
9.422	3.120	0.422	0.293	0.358	0.613	0.253	0.695	0.583
9.430	2.175	0.322	0.255	0.411	0.443	0.453	0.881	0.575
9.437	2.923	0.324	0.303	0.324	0.581	0.361	0.785	0.674
9.445	3.562	0.574	0.551	0.346	0.686	0.442	0.736	0.692
9.449	3.076	0.524	0.454	0.520	0.629	0.455	0.691	0.583
9.457	3.362	0.441	0.445	0.308	0.736	0.508	0.639	0.620
9.469	3.056	0.457	0.315	0.603	0.802	0.463	0.713	0.572
9.473	–	0.346	0.474	0.397	0.770	0.385	0.707	0.629
9.480	3.623	–	–	–	–	0.363	0.616	0.389
9.488	3.853	0.413	0.296	0.340	0.635	0.274	0.664	0.548
9.496	3.564	0.609	–	0.547	0.838	0.317	0.602	0.611
9.512	3.555	0.359	0.192	0.262	0.705	0.375	0.595	0.462
9.527	3.803	0.392	0.409	0.383	0.557	0.472	0.869	0.558
9.535	3.041	0.582	0.551	0.345	0.976	0.441	0.702	0.469
9.539	2.865	0.577	0.450	0.648	0.811	0.525	0.946	0.649
9.551	2.601	0.306	0.397	0.425	0.705	0.503	0.939	0.591
9.559	2.500	0.443	0.583	0.432	0.933	0.473	0.877	0.640
9.566	3.486	0.397	0.326	0.219	0.989	0.391	0.787	0.616
9.578	2.915	0.608	0.317	0.422	0.908	0.522	0.903	0.726
9.582	3.709	–	0.425	0.309	0.888	0.339	0.744	0.580
9.594	2.898	0.421	0.348	–	0.978	0.537	0.865	0.760
9.602	3.637	0.441	0.528	0.440	0.740	0.569	0.768	0.592
9.609	3.472	0.514	0.518	0.238	0.467	0.576	0.721	0.500
9.617	3.200	0.400	0.343	0.193	–	0.342	0.699	0.646
9.625	3.057	0.558	0.269	0.633	1.122	0.600	0.911	0.631
9.633	3.253	0.430	0.549	0.226	0.758	0.432	0.780	0.521
9.641	3.049	0.363	0.327	0.416	0.735	0.466	0.866	0.764

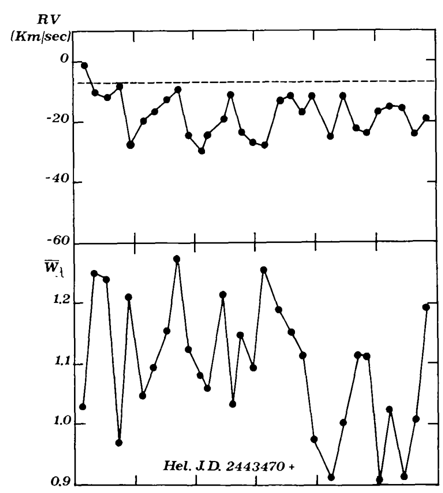

Fig. 6. Averaged *RV* and averaged *normalized* W_λ vs heliocentric Julian Days, for the metal lines at the apastron 1977 (symbols as in Figure 1).

TABLE VII (a)

RV (km s^{-1}) of metallic lines near the apastron passage of 1977

Hel. J.D. 2443470+	λ3933 (3)	λ4045 (7)	λ4063 (8)	λ4071 (9)	λ4077 (10)	λ4290 (29)	λ4481 (46)	λ4549 (53)
1.246	+ 7.6	−24.6	–	–	–	–	+ 1.7	+10.4
1.254	+14.0	–	−30.0	–	−15.3	−23.2	+ 1.8	−10.0
1.262	+49.5	–	−44.9	–	–	−40.9	–	−12.5
1.270	+21.0	–	−20.6	−16.1	+ 7.0	−26.6	–	−14.4
1.277	+ 1.6	−57.1	−45.6	–	–	–	–	− 9.0
1.285	− 6.2	−35.2	−30.7	−34.4	− 0.1	−37.4	− 7.2	− 6.3
1.293	+ 3.5	− 0.3	−27.6	–	−33.8	−37.9	−15.8	− 9.3
1.301	+ 1.7	−26.8	−23.3	−34.0	− 8.7	–	+ 3.8	− 5.6
1.309	+22.5	−12.1	−22.6	–	–	−32.1	− 7.0	− 8.2
1.316	+ 9.4	−22.1	−31.1	−43.0	−46.9	−20.2	−17.5	−23.9
1.324	−22.8	−10.2	–	–	−35.6	−83.1	− 5.7	−22.0
1.328	− 5.0	−48.5	–	−21.5	−40.4	−36.0	− 4.2	−19.3
1.340	+14.7	–	−49.5	–	−35.8	−37.1	− 1.7	− 3.9
1.344	+18.3	−10.8	−32.6	+ 2.0	−11.8	−39.7	− 2.2	− 8.9
1.352	−11.5	−23.6	−10.1	−36.9	−37.4	−31.2	−15.4	−23.3
1.359	−13.9	−10.8	−66.2	–	−31.3	−39.1	−12.1	−14.9
1.367	+19.1	− 1.1	−57.6	−28.2	−44.0	−71.2	−13.2	−31.7
1.375	+10.8	− 9.1	− 6.8	− 7.8	–	−53.1	− 8.4	−17.6
1.383	+20.5	+ 7.6	–	− 9.7	−27.7	−50.7	− 4.7	− 9.7
1.391	+15.8	−29.5	−34.1	+ 0.5	–	−34.7	− 6.6	−19.2
1.398	− 6.5	–	–	–	+ 7.8	−31.2	−20.7	− 8.1
1.410	− 4.6	−41.4	−28.3	–	−44.0	−39.9	−15.9	− 7.8
1.418	+ 9.4	+15.8	–	–	–	−31.1	− 9.9	− 6.0
1.426	+ 9.6	−35.3	−21.9	−38.4	−13.4	−53.7	−13.4	− 8.5
1.434	− 5.4	−22.9	−35.1	–	−20.8	−47.9	−17.3	−15.8
1.441	+14.9	−30.3	–	−19.8	−35.6	−35.8	+ 2.7	−15.7
1.449	+ 2.6	−18.8	−25.0	− 3.2	−20.0	−29.9	− 9.3	−12.9
1.457	− 4.5	−10.8	−34.9	+ 0.6	−20.8	−34.5	−15.7	− 6.9
1.465	−10.7	−37.0	−21.5	−46.2	−15.4	−30.3	−18.1	−12.0
1.473	+ 0.8	−25.9	− 6.2	−28.9	−25.3	−45.8	− 5.5	−18.1

The numbers in parentheses refer to the Table I.

The averaged normalized values of W_λ for the hydrogen and metal lines, reported in Figures 1–6, are obtained normalizing the values of W_λ of *each* line to its average, and then averaging the normalized values of *all* the lines for each heliocentric Julian Date.

These figures show clear variations of amplitudes in the $\overline{RV}$ curves ($\pm$ 30 km s^{-1} for hydrogen lines and $\pm$10 km s^{-1} for metal lines). Moreover, these variations are periodic and their amplitudes are stronger at periastron 1976 and 1977, weaker at apastron 1977. The $\overline{W}_\lambda$ curves do not show a similar trend at periastron. However, further elaborations of the W_λ values seem to confirm a periastron effect (see the discussion, later on).

In the hypothesis of periodic variations (pulsations) of Beta Ari, from the PLC

TABLE VII (b)

W_λ (Å) of metallic lines near the apastron passage of 1977

Hel. J.D. 2443470+	λ3933 (3)	λ4045 (7)	λ4063 (8)	λ4071 (9)	λ4077 (10)	λ4290 (29)	λ4481 (46)	λ4549 (53)
1.246	1.856	0.593	0.349	0.493	0.716	0.517	0.989	0.518
1.254	2.356	0.543	0.446	0.485	0.995	0.613	0.697	0.757
1.262	2.189	0.688	0.526	0.669	0.824	0.539	0.771	0.670
1.270	2.559	0.405	0.315	0.272	0.618	0.444	0.820	0.546
1.277	2.273	0.439	0.512	0.519	0.743	0.446	0.968	0.677
1.285	2.612	0.472	0.440	0.368	0.658	0.344	0.607	0.623
1.293	3.078	0.264	0.507	0.248	0.835	0.457	0.709	0.593
1.301	3.213	0.409	0.367	0.543	0.569	0.504	0.874	0.680
1.309	3.360	–	0.513	0.498	1.055	0.483	0.742	0.631
1.316	2.542	0.470	0.379	0.449	0.810	0.434	0.810	0.685
1.324	2.660	0.533	0.413	0.246	0.511	0.498	0.873	0.637
1.328	2.995	0.340	0.221	0.459	0.528	0.345	0.784	0.541
1.340	2.026	0.575	0.749	0.578	0.989	0.628	0.817	0.549
1.344	2.730	0.353	0.300	0.375	0.648	0.532	0.843	0.445
1.352	2.782	0.574	0.489	0.297	0.771	0.563	0.903	0.447
1.359	2.785	0.448	0.480	0.476	0.607	0.345	0.864	0.527
1.367	2.378	–	0.495	0.599	0.976	0.534	0.834	0.636
1.375	2.473	0.616	0.616	0.548	0.611	0.463	0.783	0.584
1.383	3.674	0.395	0.416	0.534	0.781	0.354	0.899	0.537
1.391	2.880	0.412	0.335	0.424	0.686	0.415	0.920	0.692
1.399	1.542	0.314	0.293	0.645	0.540	0.282	0.880	0.499
1.410	2.012	0.402	0.243	–	0.451	0.378	0.840	0.615
1.418	2.770	0.368	0.505	0.304	–	0.436	0.863	0.496
1.426	2.927	0.378	0.323	0.438	0.721	0.508	0.953	0.570
1.434	2.879	0.386	0.521	0.499	0.749	0.454	0.690	0.625
1.441	2.727	0.278	0.222	0.212	0.641	0.406	0.610	0.402
1.449	2.736	0.435	0.209	0.323	0.783	0.483	0.767	0.623
1.457	2.207	0.241	0.344	0.268	0.502	0.347	0.862	0.651
1.465	2.876	0.549	0.403	0.457	0.676	0.441	0.751	0.596
1.473	2.899	0.446	0.556	0.456	0.718	0.490	0.840	0.660

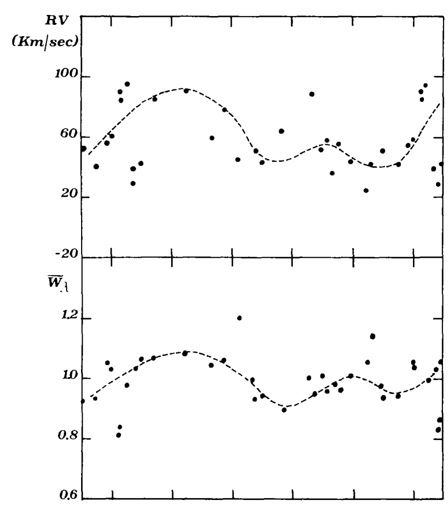

Fig. 7. *RV* and *normalized* W_λ vs phase ($P = 0^d.092$) for the Ca II K line at the periastron 1976. The dotted line is the best hand-drawn fitting.

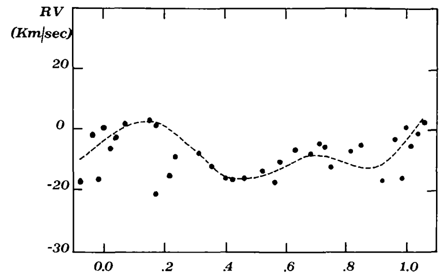

Fig. 8. *RV* vs phase ($P = 0\overset{d}{.}048$) for the ⟨Mg II⟩ $\lambda = 4481$ line at the apastron 1977 (dotted line, see Figure 7).

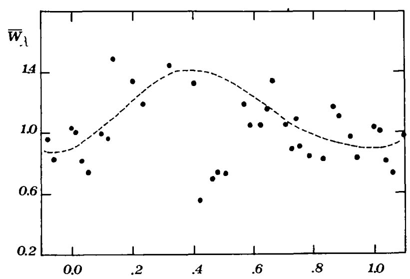

Fig. 9. *Normalized* W_λ vs phase ($P = 0\overset{d}{.}050$) for the Fe I $\lambda = 4045$ line at the periastron 1976.

relation reported by Breger (1979) we can infer an average pulsation period $P = 0.041 \pm 0.008$ days.

Nevertheless, considering the evolution diagram reported by Petersen (1975) we can infer that Beta Ari is going into the instability strip region across its blue edge; hence, we could expect one or more higher order pulsations (King *et al.*, 1973; Breger and Bregman, 1975). Moreover, beat periods of about 0.100–0.250 days could be expected (Frolov, 1975).

A periodogram analysis of the *RV* and W_λ was performed for each line and for the averages, as in our previous paper (Antonello *et al.*, 1978). The results were also verified with the empirical *cycle-count* rule proposed by Breger (1979). Periods between 0.030–0.050 days with amplitudes of 40–70‰, between 0.070–0.100 and 0.150–0.190 days with amplitudes of 10–30‰ for the single lines were found.

We could consider the smaller periods as primary ones: the above mentioned photoelectric observations by Weiss (1978), carried out a *week before* our 1977 periastron set of spectra, seem to show such a period of pulsation (~0.04 days). The longer periods could be beat pulsation periods. The variations of the W_λ(Hγ) correspond to variations of temperature of about hundred degrees (Gray, 1976). Our results seem in agreement with the theoretical expectations.

In Figures 7–9 the curves of *RV* and W_λ vs phase are plotted for some selected lines (Ca II K $\lambda = 3933$, ⟨Mg II⟩ $\lambda = 4481$ and Fe I $\lambda = 4045$).

4. Discussion

The results reported above seem to indicate a probable periastron effect in the system of Beta Ari. If we compare the *RV* values of our three sets of data we can notice that the dispersions around the averages are higher at the periastron than at the apastron passage. This effect is higher for Mg II (the dispersion at periastron is three times that at apastron) and lower for Fe II. A tidal modulation at periastron passage could produce this effect.

Furthermore, as the amplitudes of the *RV* variations a day after the periastron passage are similar to those at the apastron passage, we can infer that the periastron effect operates only some hours around this phase, according to theoretical expectations (Dommanget, 1967).

As regards the curves of the W_λ no meaningful variations of the amplitudes have been found. Nevertheless, remarkable variations of the averaged values of the three sets of results have been noticed. At periastron the hydrogen lines have higher intensities whereas the metal lines have lower intensities. These facts could be linked with Huang's hypothesis of the periastron effect (1959) and with the reflection effect which implies an increase of temperature (Russell and Merrill, 1952). Further, this effect is unimportant *a day after* the periastron passage, according to the *RV* amplitude variations. An opposite behaviour can be noticed in Ca II and Mg II line intensities.

The study of the asymmetries of the Ca II K line has allowed to single the following phenomena: (1) a strong asymmetry during the periastron passage; (2) a variation of the asymmetry, linked to the variation of the *RV*, that could be connected to the Schuster effect observed in Cepheids.

The asymmetry of the lines has been estimated as the ratio of the difference between the *partial* equivalent widths of the blue and red 'half-lines' (obtained crossing the maximum depth of the line with a vertical axis) to the *total* equivalent width of the line. Hence the corresponding value is *positive* or *negative* according to the blue wing *more* or *less* large than the red wing.

At periastron we have found a strong positive asymmetry which falls off quickly three

TABLE VIII
Values of the asymmetry of Ca II K line near the periastron passage of 1976

Hel. J.D. 2443090+	W_λ (Å)	Asymmetry (see text)
7.352	3.86	10.4
7.383	3.89	6.9
7.395	3.72	5.9
7.430	3.96	3.0
7.504	3.73	2.7
7.535	3.85	2.6
7.543	3.62	2.5

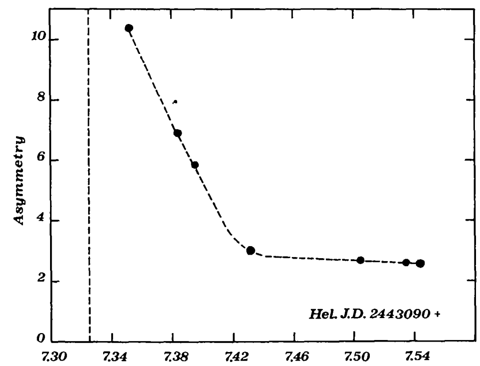

Fig. 10. Asymmetry of the Ca II K line vs heliocentric Julian Days, around the periastron passage 1976 (symbols as in Figure 1).

TABLE IX
Values of the asymmetry of Ca II K line corresponding to RV phases (Schuster effect)

Hel. J.D. 2443410+	W_λ (Å)	Asymmetry (see text)	Rad. vel. phase
9.430	2.18	+3.7	Maximum
9.512	3.55	+1.1	Ascending branch
9.551	2.60	−0.8	Minimum
9.582	3.71	−0.3	Descending branch
2443470+			
1.254	2.36	0.0	Ascending branch
1.285	2.61	−5.0	Minimum
1.309	3.36	+5.1	Maximum
1.328	2.99	−0.7	Ascending branch
1.344	2.73	+3.3	Maximum
1.352	2.78	+0.7	Descending branch
1.359	2.79	−7.5	Minimum
1.367	2.37	+1.7	Maximum
1.410	2.01	0.0	Ascending branch
1.449	2.74	+1.1	Descending branch

hours after the passage. In Table VIII and figure 10 are reported and drawn the values of the asymmetry of this line, around the periastron passage. A similar phenomenon has been ascertained for the hydrogen lines also.

The above-mentioned Schuster effect is characterized by an asymmetry of the line profiles related to the RV of the star atmosphere (Abhyankar, 1964, 1965): in a steady atmosphere ($RV = 0$) the lines have symmetric profiles, in a contracting atmosphere ($RV > 0$) the blue wing is larger, in an expanding atmosphere ($RV < 0$) the red wing is larger. This effect is recognizable in the variation of the Ca II K line of the spectra taken away from the periastron passage. In Table IX are reported tne values of this effect.

5. Conclusions

From the foregoing results and discussion we can draw the following conclusions. The analysis of the RV and W_λ of Beta Ari at periastron and apastron shows periodic variations (pulsations) in agreement with the observational and theoretical expectations for a Delta Scuti variable of this kind.

The comparison between the RV and W_λ curves of the H_γ and Ca II K lines shows a trend similar to that of other classical Delta Scuti stars: f.i. ρ Pup (Dravins *et al.*, 1977), δ Sct and δ Del (Kuhi and Danziger, 1967). Nevertheless, for Hγ the comparison with the RV curve is lacking. The increased amplitudes of the RV curves, the remarkable variations of the averaged values of W_λ (normalized), for the hydrogen and metal lines (with an opposite effect for the Ca II K and Mg II lines), seem to point out a tidal modulation of the pulsations during some hours about the periastron passage.

Moreover, the variations of the asymmetries of the hydrogen and Ca II K lines, linked to the variations of the RV, seem similar to the Schuster effect observed in classical Cepheids.

A strong positive asymmetry (the blue wing larger than the red wing) during few hours about the periastron passage seems to show some tidal transient phenomena also. A 'bump' quite evident in the RV and W_λ curves of the Ca II K line (see Figure 7) could be in agreement with the theoretical forecasts of Aleshin (1964).

Finally, we wish to point out the following peculiarities of Beta Ari: its rotational velocity ($v \sin i = 70$–$80\,\mathrm{km\,s^{-1}}$) is quite low for its spectral type and luminosity class (115–150 $\mathrm{km\,s^{-1}}$; Allen, 1973), and considerably lower than its orbital velocity at periastron ($\sim 270\,\mathrm{km\,s^{-1}}$). The periastron effect, foreseen by some above-mentioned authors could have produced this peculiar situation and should diminish progressively with time this effect (Zahn, 1970).

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