A SURFACE MAGNETIC FIELD STUDY OF Ap STAR 78 VIRGINIS

T. A. Ryabchikova, E. S. Davydova
The Astronomical Council of the USSR Academy of Sciences, Pyatnitskaya Str., 48, Moscow, USSR

D. Z. Kolev
Bulgarian Academy of Sciences, Department of Astronomy, Lenin Bul., 72, Sofia, 1184, Bulgaria

1. INTRODUCTION

The discovery of a strong variable surface magnetic field (B_s) in four Ap stars: HD 215441, β CrB, HD 126515 and 53 Cam (Preston, 1969a; Wolff and Wolff, 1970; Preston, 1970; Huchra, 1972) changed our knowledge about magnetic field geometry, formerly based only on effective field measurements (B_e). Unfortunately, for most of Ap stars the measurement of a full Zeeman pattern of a spectral line in unpolarized light is practically impossible because the very small splitting for B_s<=5 kGs cannot be resolved with the accuracy of modern spectroscopy. Therefore, indirect methods of estimation of B_s were developed using the effect of a magnetic field on the intensity and width of spectral lines. One of these methods, a photometric one (Cramer and Maeder, 1980) is based on the dependence of the λ 5200 depression on the magnetic field strength. Two other methods, spectroscopic ones, are based on the additional widening of spectral lines introduced by the magnetic field. Preston s method (Preston, 1971) makes it possible to estimate B_g by measuring the full widths of the spectral lines. This method requires high dispersion spectra. The method of the magnetic field estimation based on the magnetic intensification effect (Hensberge and De Loore, 1974; Ryabchikova and Piskunov, 1984) (curve of growth method) permits us to use a lower dispersion. In this paper we present some results of an investigation of the variation with the rotation of the surface magnetic field for the Ap star 78 Vir using the curve of growth method.

2. SPECTRAL DATA AND DATA REDUCTION

We studied 14 spectra of 78 Vir obtained with the 2-m telescope in NAO BAS (9 spectra) by D. Kolev, with the 2.6-m telescope in Crimea (3 spectra) by T. Ryabchikova and with the 6-m telescope in SAO AS USSR (2 spectra) by I. Romanyuk. A dispersion of the spectra is 8-9 A/ee. The latter two spectra were obtained with the Zeeman analyzer. In order to obtain the equivalent width in the unpolarized light the values of W_λ for both right and left-hand polarization were summed. An accuracy of values W_λ was increased by the averaging of equivalent width for the latter two spectra. Spectrograms were reduced on the microdensitometers MD-6 Joyce Loebl and 3CS Joyce Loebl with the help of the software developed in the Astronomical Council of USSR AS (Piskunov et al., 1984).

3. AN ESTIMATION OF THE SURFACE MAGNETIC.FIELD OF 78 VIR

A curve of growth method (Ryabchikova and Piskunov, 1984) was applied to estimate the value of the surface magnetic field B_s. Only FeI and FeII lines were used. The theoretical curves of growth were calculated on the basis of Kurucz model with 9500 K and log g = 4.0 (Kurucz et al., 1974). Oscillator strengths were taken from Martin et al. (1987), and Lande factors Z from Beckers (1969). The classical damping constant was taken for FeI lines while $\gamma = 10\ \gamma_{cl}$, for FeII ones. Equivalent widths obtained from the spectra are presented in Table 1. Phases were calculated according to ephemeris taken from Preston (1969).

$$JD = 2434816.9 + 3.7220\ E$$

Estimates of the surface field B_s, values of the microturbulence parameter, and of the relative iron abundance are given in Table 2.

4. DISCUSSION

In Fig. 1 the phase variation of the surface magnetic field B_s (1b, c) of 78 Vir is compared with that of the effective field B_e (1a) from Borra and Landstreet (1980) and Borra (1980a). One sees that both values vary practically in phase. Unfortunately, the absence of observations in the phase interval 0.2-0.55, which corresponds to the minimum field, does not permit us to say whether the small phase shift is real. In general, the behaviour of B_s for FeI and FeII lines is similar, although for the FeII lines the value of the field and the amplitude of variation are smaller (Fig. 1 b, c). We noticed this fact earlier (Ryabchikova and Piskunov, 1984) for 78 Vir and for some other peculiar stars. Borra (1980b) has calculated magnetic field configurations for 78 Vir on the basis of the known effective field variations. According to his model 78 Vir has a dipole field with the surface field B_s = 2.3 kGs near the phase 0.50. In this paper he also considered both the theoretical and observational evidence in favour of the conclusion that the maximum of B^s coincides with the narrower extremum of the Be photographic curve. According to observations by Preston (1969b) this extremum has a phase 0.00. Thus, the curve for the B_s variations obtained from the FeI lines is in a good agreement both with the value of the surface field at maximum and with the phase variations predicted by Borra's model. Our estimate of B_s at minimum seems to be low when compared to the

Table 1. Equivalent width measurements of the FeI and FeII lines

spectrum No	450	1111	489 490	3	379	380	1044	4	5	435	539	395	396
Observatory	NAO BAS	NAO BAS	SAO	CrAO	NAO BAS	NAO BAS	NAO BAS	CrAO	CrAO	NAO BAS	NAO BAS	NAO BAS	NAO BAS
Phase	0.109	0.173	0.184	0.573	0.700	0.702	0.778	0.818	0.831	0.844	0.956	0.968	0.971
FeI			Equivalent widths in mA										
4009.715	43	44	-	67	76	78	61	79	-	86	71	70	60
4021.870	66	75	55	77	71	84	70	83	96	82	90	62	63
4063.596	162	119	156	200	185	153	153	170	156	168	157	162	160
4071.740	101	93	90	117	134	125	112	132	116	115	122	114	118
4132.060	126	109	130	175	-	-	-	172	164	188	184	169	143
4143.870	113	102	119	130	136	130	135	126	144	128	135	140	131
4187.044	-	80	95	127	-	128	102	110	125	112	114	114	101
4210.352	101	84	79	106	119	118	90	118	118	116	117	102	115
4219.364	68	76	74	92	108	109	94	88	113	100	97	88	110
4235.943	109	95	99	145	148	120	106	143	138	124	138	120	135
4250.125	120	96	77	-	151	115	125	-	-	125	117	121	127
4267.828	35	49	48	60	75	60	53	60	-	58	40	55	45
4271.159	141	109	92	140	153	142	128	130	116	120	145	133	134
4271.763	168	132	116	188	188	184	164	170	164	160	192	187	159
4299.241	92	96	86	148	172	146	129	132	129	122	158	137	133
4383.547	139	120	110	152	174	165	136	172	160	138	120	175	150

Table 1. (continued)

spectrum №	450	1111	489 490	3	379	380	1044	4	5	435	539	395	396
Observatory	NAO BAS	NAO BAS	SAO	CrAO	NAO BAS	NAO BAS	NAO BAS	CrAO	CrAO	NAO BAS	NAO BAS	NAO BAS	NAO BAS
Phase	0.109	0.173	0.184	0.573	0.700	0.702	0.778	0.818	0.831	0.844	0.956	0.968	0.971
4404.753	112	129	106	141	163	164	158	159	184	125	159	163	129
4408.419	61	66	41	88	56	81	41	80	56	48	78	66	42
4415.125	-	117	101	99	-	-	112	116	96	102	134	114	89
4442.343	-	82	-	-	-	-	-	-	-	-	-	82	-
4443.201	-	50	-	-	-	-	-	-	59	43	86	38	45
4446.554	97	73	77	83	105	91	114	96	85	90	109	120	125
FeII													
3906.038	-	-	-	-	-	-	86	-	-	-	-	95	75
3938.966	88	85	-	-	84	74	97	-	-	96	-	85	72
4124.787	72	70	38	68	95	74	71	77	77	75	71	81	82
4178.848	118	105	121	155	117	138	121	150	170	148	142	148	136
4273.315	93	122	98	162	181	161	134	168	140	126	159	157	138
4351.762	152	161	127	-	191	-	208	-	-	-	-	198	-
4369.398	-	-	-	-	-	-	120	-	-	-	-	-	-
4385.385	119	142	99	166	165	174	149	182	170	154	157	176	165
4416.817	131	137	113	158	159	146	154	160	139	122	175	158	161
4491.398	97	96	102	-	126	112	105	-	-	97	104	122	139
4508.280	112	147	105	141	146	177	159	160	146	138	157	147	154
4520.225	115	141	111	130	161	185	161	146	128	130	161	154	139
*522.624	167	170	147	180	211	231	215	-	212	181	-	214	201
4541.523	117	104	122	123	-	143	93	-	117	121	109	147	133

Table 1. (continued)

spectrum №	450	1111	489 490	3	379	380	1044	4	5	435	539	395	396
Observatory	NAO BAS	NAO BAS	SAO	CrAO	NAO BAS	NAO BAS	NAO BAS	CrAO	CrAO	NAO BAS	NAO BAS	NAO BAS	NAO BAS
Phase	0.109	0.173	0.184	0.573	0.700	0.702	0.778	0.818	0.831	0.844	0.956	0.968	0.971
4555.890	182	178	160	-	191	-	-	-	-	188	-	-	-
4576.331	133	112	93	109	155	134	134	127	130	84	160	139	143
4582.895	101	103	92	-75	110	117	136	119	112	112	129	112	94
4583.850	191	264	194	242	263	240	254	279	251	217	262	268	264
4620.513	74	111	77	70	117	117	118	110	120	79	109	-	126
4629.336	149	124	105	95	115	166	143	144	140	-			
4635.327	83	84	79	-	114	106	104	-	-	-	131	100	103

model predictions. However, as we mentioned above the absence of observations in the phase interval 0.2 - 0.55 does not permit us to draw a firm conclusion on the reality of this discrepancy. Additional, observations in these phases are needed. The 2-m telescope of the NAO BAS seems to be quite suitable for this purpose.

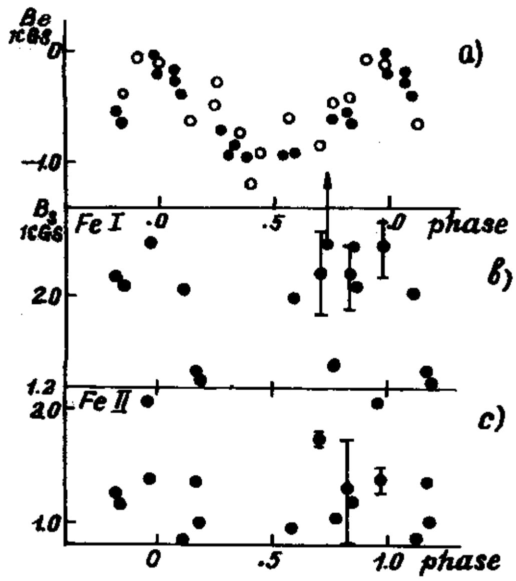

Fig. 1. Variations of the effective B_e (a) and surface B_s (b, c) magnetic field for the Ap star 78 Vir.
• – B_e photoelectric measurements from polarization in FeII 4520.22 by Borra (1980a)
∘ – B_e photoelectric measurements from polarization in H_β by Borra and Landstreet (1980).

5. CONCLUSION

The method of surface magnetic field determination for the peculiar stars based on the magnetic intensification effect (the curve of growth method) makes it possible to study phase variations of the magnetic field B_s in those cases where the direct method based on the line splitting fails. It would be interesting to apply this method to the study of the surface magnetic field variations of other peculiar stars, primarily of α^2 CVn.

Table 2. Measurements of the surface magnetic field, micro-turbulent velocity and iron abundance in the atmoiphere of 78 Vir.

Phase	FeI				FeII			
	N	V km/s	B kGs	log Fe/H	N	V km/s	B kGs	log Fe/H
0.109	18	2.00	2.05	-3.62	19	1.00	0.82	-3.27
0.173	21	1.00	1.34	-3.36	19	1.00	1.37	-3.31
0.184	19	1.00	1.24	-3.39	18	1.00	0.99	-3.57
0.573	19	2.00	1.98	-3.26	14	1.00	0.93	-3.20
0.700	17	2.00	2.60	-3.35	18	2.00	1.80	-3.23
0.702	18	2.00	1.83	-3.19	17	1.00	1.68	-3.12
0.778	19	2.00	1.41	-3.38	20	2.00	1.02	-3.20
0.818	19	2.00	1.91	-3.22	12	1.00	1.73	-3.16
0.831	18	2.00	2.47	-3.49	14	2.00	0.80	-3.18
0.844	21	2.00	2.11	-3.47	16	1.00	1.17	-3.19
0.956	21	2.00	2.72	-3.45	16	1.00	2.06	-3.23
0.968	22	2.00	2.75	-3.97	18	2.00	1.48	-3.20
0.971	21	2.00	2.19	-3.57	18	1.00	1.28	-3.09

REFERENCES

Beckers, J. M.: 1969, A Table of Zeeman Muitiplets, Sacramento Peak Observatory, Phys. Sci. Research Papers, No. 371.
Borra, E. F.: 1980a. Astrophys. J., v. 235, 911.
Borra, E. F.: 1980b. Astrophys. J., v. 235, 915.
Borra, E. F., Landstreet, J. D.: 1980, Astrophys. J. Suppi. Ser., v. 42, 421.
Cramer, N., Maeder, A.: Astron. Astrophys., v. 88, 135.
Hensberge, H., Be Loore, C: 1974, Astron. Astrophys., v. 37, 367.
Huchra, J.: 1972, Astrophys. J., v. 174, 435.
Kurucz, R. L., Peytreeann, E., Avrett,E.: 1974. Blanketed Model Atmospheres for Early-Type Stars. Smithsonian Inst. Washington, DC.
Martin, G. A., Fuhr, J. R., Wiese, N. L.: 1987. NSRDS-NBS (preprint).
Piskunov, N. E., Ptitsyn, D. A., Ryabchikova, T. A., Khokhlova, V. L.: 1984, Nauchnye Informatsii, Astr. Sovet Akademii Nauk SSSR, v. 54, 45.
Preston, G. N.: 1969a, Astrophys. J., v. 156, 967.
Preston, G. N.: 1969b, Astrophys. J., v. 158, 243.
Preston, G. N.: 1970, Astrophys. J., v. 160, 1059.
Preston, G. N.: 1971, Astrophys. J., v. 164, 309.
Ryabchikova, T. A., Piskunov, N. E.: 1984, In: Magnetic Stars, Eds. V. Khokhlova et al., Salaspils, 27.
Wolff, S. C, Wolff, R. J.: 1970, Astrophys. J., v. 160, 1049.