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PECULIAR A STARS: STUDY OF 73 DRACONIS

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RIASSUNTO. — 73 Dra è una stella magnetica spettrovariabile. Mentre il campo fluttua in modo irregolare fra — 700 e 0 gauss, le righe spettrali variano regolarmente con periodo $20^d.27$. Tanto le righe del Cr che dell'Eu variano in fase, contrariamente a quanto avviene nella maggioranza delle stelle Ap. Tanto le righe del Mg II, Ca II, Ti II, Cr II, Fe I, Fe II, Sr II, Eu II che quelle di Balmer variano in fase. Delle 25 righe di cui è stata studiata la variazione solo la riga non identificata λ 4423 non è variabile.

Lo spettro di righe metalliche di 73 Dra è molto simile a quello di α Per (F5 I_b) e di 41 Cyg (F2 III) salvo per le righe del Ca I che sono assenti in 73 Dra, e Ca II che è circa 9 volte più debole in 73 Dra, e per la maggior forza delle righe del Mg II, Cr II. Lo spettro dell'idrogeno e l'indice di colore indicano un tipo prossimo ad A0. I profili delle righe di Balmer indicano una classe di luminosità IV o V, mentre il numero di righe di Balmer visibili indica una classe Ib. Si costruisce la curva di crescenza impiegando le righe del Fe I e Fe II. Si trova come parametri più probabili per l'atmosfera di 73 Dra: $\theta_{ion} = 0.80$; $\log P_e = 1.2$; v(Fe I) = 7.6 km/s; v(Fe II) = 9.5 km/s. Le principali anomalie nelle abbondanze consistono in un eccesso di Mg, Cr, Mn, Ce, Eu, Gd e in un difetto di Ca. La composizione chimica è molto simile a quella di α^2C Vn e di HD 133209.

ABSTRACT. — 73 Dra is a magnetic spectrovariable star. The magnetic field fluctuates irregularly between — 700 and 0 gauss. The spectral lines on the contrary vary regularly in 20.27 days. Cr and Eu lines vary in phase, at contrast to the majority of the other Ap stars. The lines of Mg II, Ca II, Ti II, Cr II, Fe I, Fe II, Sr II, Eu II and the Balmer lines all vary in phase.

Among the 25 lines for which the variability has been studied, the only invariable line is the unidentified line λ 4423. The spectrum of metallic lines is very similar to the spectrum of α Per (F5 I b) and 41 Cyg (F2 III) except for the Ca I lines which are absent in 73 Dra, for the Ca II line which is 9 times weaker in 73 Dra, and for the lines of Mg II and Cr II which are stronger. The hydrogen spectrum and the color index indicate a spectral type A0. The Balmer line contours indicate a luminosity class IV or V, while the number of visible Balmer lines suggests a luminosity class Ib. The curve of growth is constructed using the lines of Fe I and Fe II. The more probable parameters for the atmosphere of 73 Dra are $\theta_{ion} = 0.80$; log. $P_e = 1.2$; v(Fe I) = 7.6 km/s; v(Fe II) = 9.5 km/s. The chemical composition is very similar to that of α^2 C Vn and HD 133209. An overabundance is found for Mg, Cr, Mn, Ce, Eu, Gd and a defect of Ca.

(*) Ricevuta il 26 maggio 1962.

INTRODUCTION

73 Draconis (HD 196502) has been classified A2p according to the HD catalogue, the main peculiarities being the exceptional strength of λλ 4077 Sr II, 4128 Si II and 4131 Si II. It was recognized as a spectrovariable star of the same type as α^2 C Vn by Morgan (^{1}) in 1933. He concluded that 73 Dra, in spite of its many peculiar features, is definitely lower in effective excitation, than α^2 C Vn. Another investigation of the variability of the spectral lines was made by Durham (^{2}) in 1943. It was later included in the observational program of magnetic stars by Babcock (^{3}) who found irregular fluctuations in the magnetic field. On 12 plates measured by Babcock the field has values generally negative fluctuating between — 700 gauss and 0 and only one plate shows a weak positive field. The results of these earlier investigations present several discrepancies among them concerning the intensity and variability of spectral lines. It is therefore important to study this star quantitatively especially since Morgan, Durham and Babcock give only qualitative estimated intensities.

Twenty spectrograms of 73 Draconis were studied (Table I) partly taken with the Zeiss one prism spectrograph (dispersion 35 A/mm at Hγ) and partly with the new grating spectrograph (35 A/mm).

TABLE I

Date	Spectrogram	U.T.	Phase
Oct. 3, 1957	HT 543	20^h37^m	0.236
	HT 544	21 15	0.236
Oct. 4, 1957	HT 545	21 18	0.287
Oct. 5, 1957	H 546	18 45	0.333
	H 547	19 33	0.333
Oct. 6, 1957	H 549	18 44	0.380
	H 550	19 18	0.380
Oct. 8, 1957	HT 554	20 10	0.481
Oct. 13, 1957	H 561	19 12	0.726
	H 562	19 34	0.726
Oct. 14, 1957	HT 565	19 35	0.776
Oct. 29, 1957	HT 567	20 15	0.518
	HT 568	20 50	0.518
Oct. 30, 1957	HT 572	19 25	0.568
	HT 573	19 58	0.568
Aug. 16, 1961	Fa 19	19 55	0.945
Aug. 17, 1961	Fa 21	19 25	0.976
	Fa 22	19 35	0.976
Aug. 18, 1961	Fa 29	20 25	0.045
Aug. 19, 1961	Fa 30	19 50	0,095

SPECTRAL VARIATIONS

73 Dra is a periodic spectrovariable. The period was estimated to be 20.7 days by Morgan (^{1}); Durham (^{2}) gave a new value of 20.27 days based on the variation of λ 4205 Eu II. Using as zero phase the epoch of maximum intensity for Eu II we have:

$$\text{Epoch of maximum Eu II} = \text{J D } 2430678{,}22 + 20.27 \text{ E}$$

Durham remarked that the minima are broader than maxima; and that certain lines of Ca II, Ti II, and Sr II vary in phase with Eu II. The only disagreement that Durham finds with Morgan concerns the line λ 4215 Sr II, which Morgan found to be at maximum when Eu II was at minimum. According to Durham several lines of Fe I, Fe II, Si II, Cr II, Mg II are not variable.

We have computed the phases for our observations (see Table I) using the elements given by Durham. We have determined the intensity variations for 23 lines of Mg II, Ca II, Ti II, Cr II, Fe I, Fe II, Sr II, Eu II and for the unidentified line λ 4423. The intensities given in fig. 1

TABLE II

Line	Morgan	Durham	This work	R_c	
				max	min
3933 Ca II	—	in phase with 4205	in phase with 4205	0.80	0.45
4481 Mg I	—	not variable	» » » »	0.70	0.38
4558 Cr II	—	» »	» » » »	0.70	0.30
4588 Cr II	—	» »	» » » »	0.70	0.35
4501 Ti II+ Fe II	in phase with 4205	in phase with 4205	» » » »	0.55	0.25
4549 Ti II+ Fe II	»	» » » »	» » » »	0.55	0.30
4571 Ti II+ Fe II	»	» » » »	» » » »	0.52	0.25
4205 Eu II	variable	variable	variable	0.68	0.23
4215 Sr II	in opposition of phase	in phase with 4205	in phase with 4205	0.80	0.33
4077 Sr II	—	» » » »	» » » »	0.88	0.40

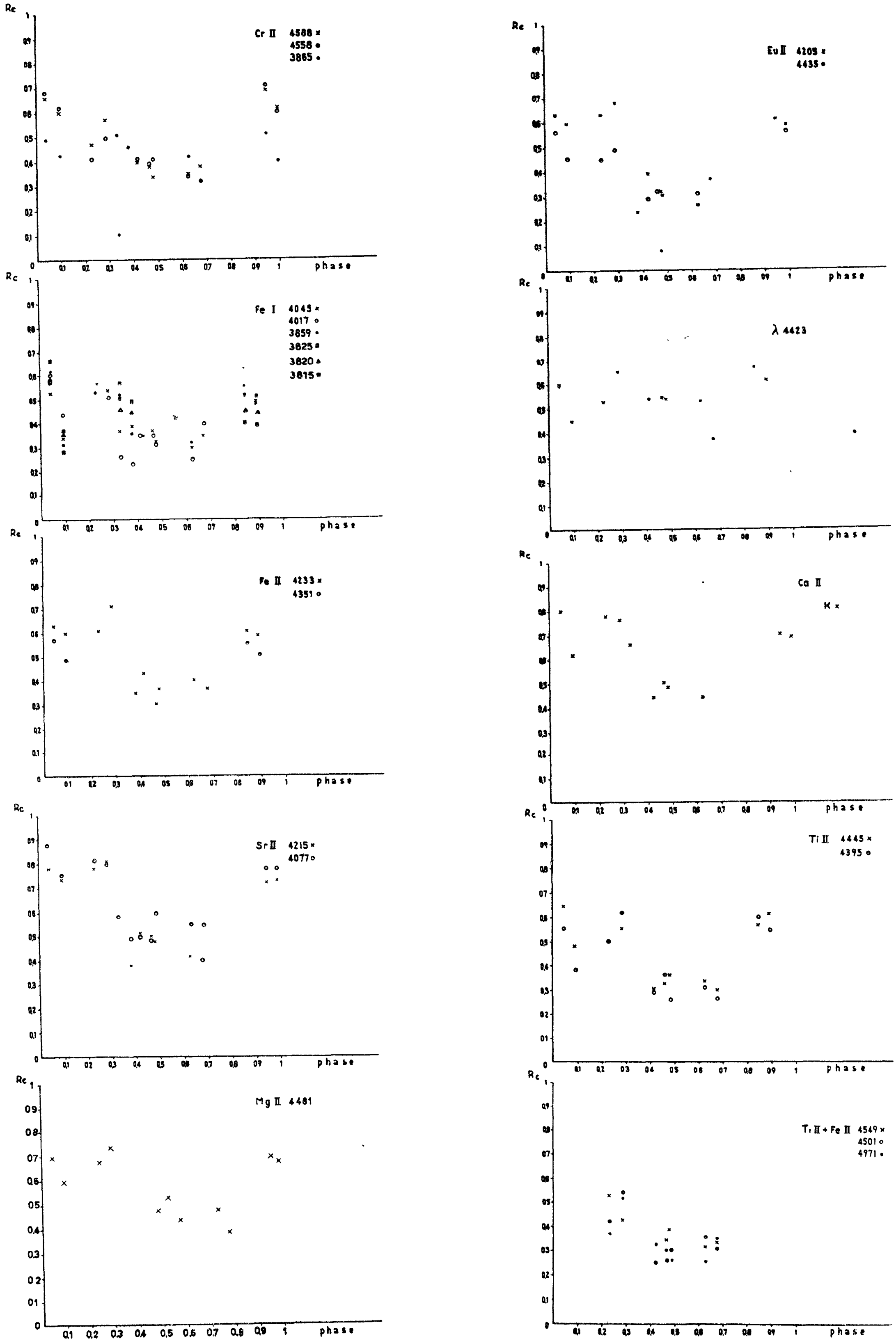
Rc
Cr II 4588 × 4558 ● 3865 •
Eu II 4205 × 4435 •
Fe I 4045 × 4017 ○ 3859 • 3825 ■ 3820 ▲ 3815 ●
λ 4423
Fe II 4233 × 4351 ○
Ca II K ×
Sr II 4215 × 4077 ○
Ti II 4445 × 4395 ○
Mg II 4481
Ti II + Fe II 4549 × 4501 ○ 4971 •
0 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1
0 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1 phase

Fig. 1

are the average of the central depths of the spectrograms of the same night. All these lines vary in phase and the only line which is not variable is λ 4423. The amplitude of variation is slightly larger for λ 4205 Eu II and λλ 4215 and 4077 Sr II, and about the same for all the other lines, in contrast with the results of Durham. Table II gives a comparison of our results with those of Durham and Morgan.

Our results using the phases computed with the elements given by Durham in 1943 show that the period has remained constant. This constancy in the period suggests that it is improbable that such marked differences in the type of variations as those found by Morgan, Durham and us are real. We believe that quantitative precise measurements repeated at long intervals of time are necessary to confirm the behavior of this star.

One peculiarity of 73 Dra with respect to the other Ap stars is the following: the chromium lines vary in phase with europium lines, while these two groups of lines in the majority of the magnetic spectrovariables vary in opposition of phase.

Also the Balmer lines have variable intensities in phase with the variations of the other lines. Fig. 2 shows that the equivalent widths of H_γ and H_δ vary from 16 A and 18 A respectively at maximum to about 11 A and 10.5 A at minimum respectively.

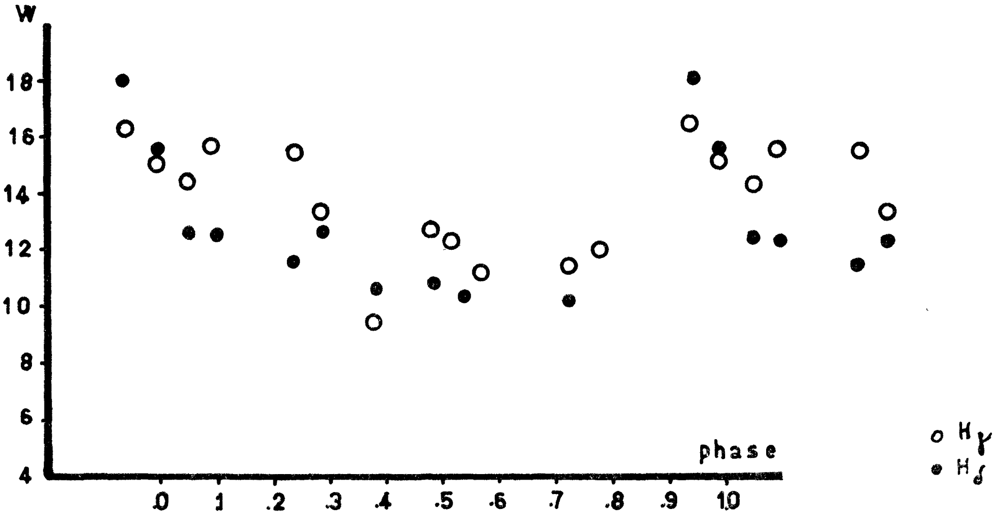

Fig. 2

Fig. 3 shows the variations of the magnetic field observed by Babcock (3). We computed the phases using the data of Durham (2). There is some weak indication that the field is generally changing (with some

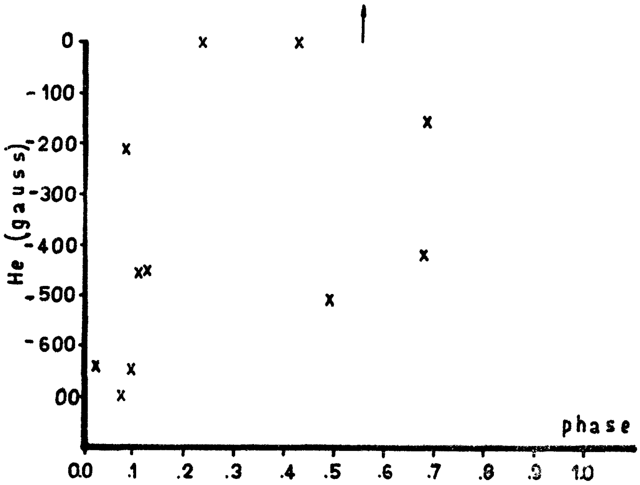

Fig. 3

irregular fluctuations) in opposition of phase with the line intensity variations. To confirm this more observations will be necessary.

Since all the lines, of high excitation potential as the Balmer lines, and of low excitation potential as the metallic lines vary in phase, it proves that variations of temperature or density are not responsible for these line variations. If it is confirmed that the magnetic field is irregular it is improbable that the regular variations of the lines are produced directly by it.

The main points of disagreement between our results and those of Morgan (who studied spectrograms having about the same dispersion as ours) are summarized as follows:

a) λ 4215 Sr II is always weaker than λ 4077, in agreement with the laboratory intensities ([4]). The contrary was found by Morgan who observes that « the line Sr II 4077 is of moderate intensity, while the other component of the ultimate doublet λ 4215 is the strongest line in the spectrum with the exception of the Balmer series of hydrogen. The difference in intensity of the two lines is marked ».

Moreover we did not observe the blend on the violet side of λ 4215 which Morgan found.

b) The K line of Ca II is always stronger at least of 20% than the other metallic lines in the same spectral region; Morgan on the contrary observed that they were all about of the same intensity.

c) We do not observe an amplitude of variation for λλ 4549, 4541, 4571 Ti II greater than for the other Ti II lines.

d) According to Morgan the unidentified line λ 4423 seems to vary in intensity, but without correlation with the period of 20 days found for the other lines. Morgan observes that it is possible though not probable that the variation is not real. From our measurements λ 4423 is the only line which is constant within the order of the errors.

e) According to Morgan many lines of Cr I are present, and he has classified 73 Dra as a chromium star. We also found several lines of Cr I but their intensity is not exceptional compared with the other metallic lines.

Many strong lines of Fe I, Fe II, Cr II are present. There is no trace of Ca I lines; also the strongest line of Ca I, λ 4226, if present gives a negligible contribute to the blend with λ 4227 Fe I, because the intensity of the blend can be explained by the Fe I line alone.

ATTEMPTS FOR A CLASSIFICATION OF THE SPECTRUM OF 73 DRACONIS.

The intensities of the metallic lines in the spectrum of 73 Dra are decidedly stronger than in a normal A2 type star. We have compared 73 Dra with 9 normal stars; we list here a few remarks (see also fig. 4).

Comparison with:

α Lyrae A0 V: all the lines of neutral and ionized metals are five to ten times stronger in 73 Dra; 4481 Mg II and 3933 Ca II are about twice as strong in 73 Dra. The Balmer lines are slightly stronger in α Lyrae.

ν Cephei A2 I_a: all the Fe I lines are three or four times stronger in 73 Dra. Ca II, Mg II, Fe II, Ti II and Cr II lines have on the average about the same intensity. Sr II lines are five times stronger in 73 Dra.

41 Cygni F2 III: the Fe I lines and the Ti II, Cr II, Fe II, Mg II, Sr II lines are almost equal or slightly stronger in 73 Dra. K Ca II is 9 times stronger in 41 Cyg.

ω Piscium F4 IV: the lines of Fe I have almost the same intensity in the two stars. Fe II, Cr II, Sr II, Ti II are slightly stronger in 73 Dra.

α Persei F5 I_b: The lines of Fe I, Fe II, Mn I, Ti II, Sr II have almost the same intensity in both stars. Mg II, Sr II and Cr II are stronger in 73 Dra.

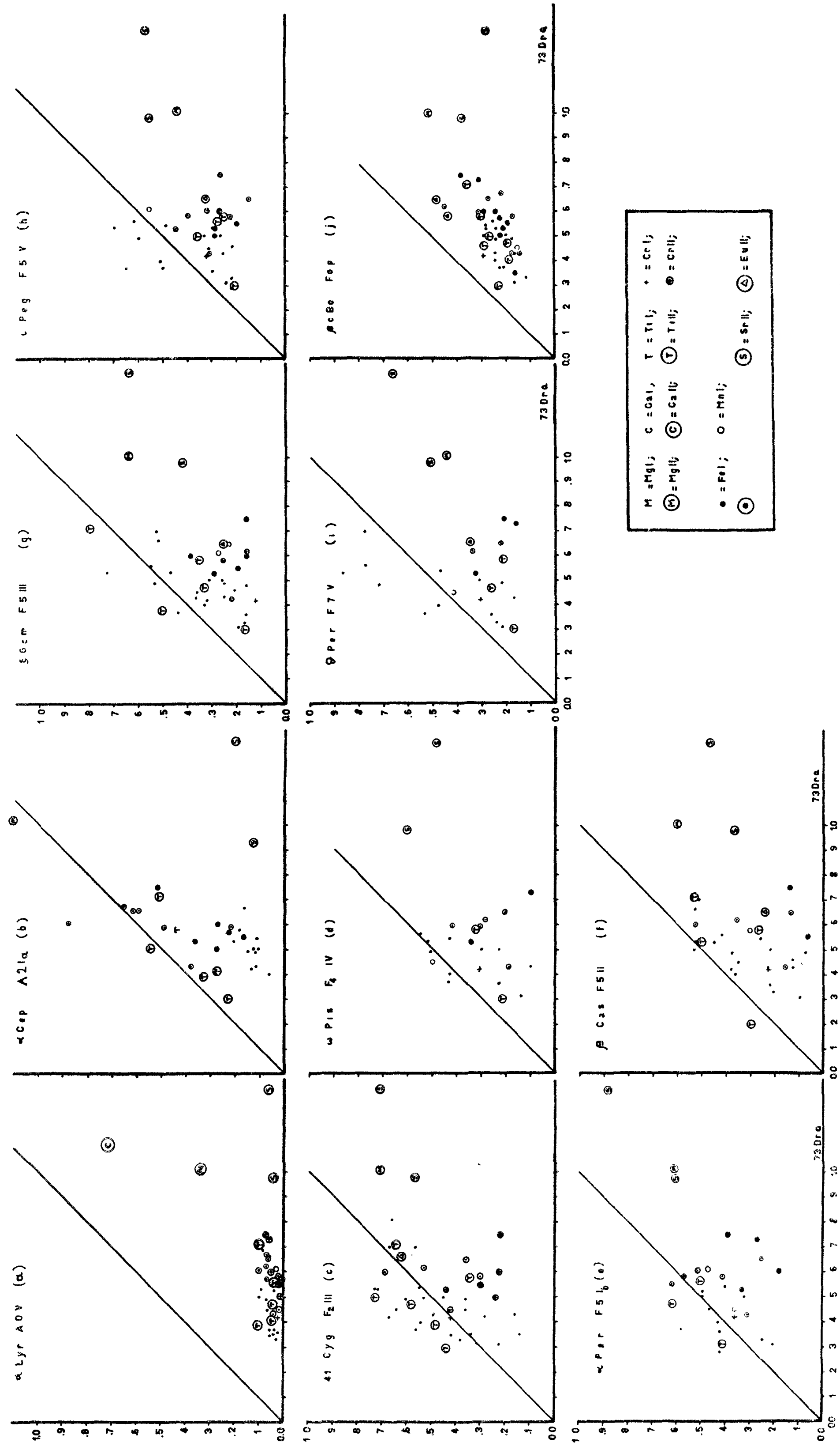
α Lyr A0V (a)
α Cep A2Iα (b)
41 Cyg F2 III (c)
ω Psc F4 IV (d)
α Per F5 Ib (e)
β Cas F5 II (f)
ξ Gem F5 III (g)
ι Peg F5 V (h)
θ Per F7 V (i)
β CBo F0p (j)
73 Dra
0.0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
0.0 1 2 3 4 5 6 7 8 9 10
M = MgI; C = CaI, T = TiI; + = CrI;
Ⓜ = MgII; Ⓒ = CaII; Ⓣ = TiII; ⊛ = CrII;
• = FeI; o = MnI;
⊙
Ⓢ = SrII; Ⓐ = EuII;

Fig. 4

β Cassiopeiae F5 II: Same remarks as for ω Piscium.

ξ Geminorum F5 III: Same remarks as for ω Piscium and β Cassiopeiae.

ι Pegasi F5 V: The Fe I lines are generally stronger in ι Peg. Lines of ionized metals are stronger in 73 Dra.

θ Persei F7 V: Some remarks as for ι Pegasi.

From these comparisons it follows that the degree of ionization of 73 Dra is lower than in ν Cephei and higher than in ω Piscium, β Cassiopeiae, ξ Geminorum, ι Pegasi and θ Persei and almost equal to that of α Persei and 41 Cygni. The metallic spectrum is very similar to that of α Persei with the important exception of λ 3933 Ca II which is about ten times weaker and the absence of Ca I lines; Cr II and Mg II lines are generally stronger in 73 Dra.

The intensity of the Balmer lines and K line of Ca II as well as the B-V color index are characteristic of an A2 type star; the Balmer lines suggest a luminosity class IV. The other two magnetic stars with metallic spectrum similar to the spectrum of 73 Dra are γ Equ and β C Bo. These two stars have strong Balmer lines corresponding to a spectral type A3 V, definitely indicating a luminosity lower than that of 73 Dra. The metallic line spectrum of γ Equ is very similar to the spectrum of α C Mi (F5 IV) (5). 73 Dra is very similar to α Per (F5 Ib) and β C Bo (6) falls between. Table III and fig. 4j give a direct comparison between the metallic spectrum of 73 Dra and the other magnetic stars.

TABLE III

line	γ Equ	β C Bo	ε U Ma	73 Dra	α^2 C Vn
4481 Mg II	0.51	0.52	0.35	1.04	0.23
3933 Ca II	7		0.35	1.11	0.16
4254 Cr I	0.17	0.29		0.42	0.07
4558 Cr II	0.19	0.38	0.15	0.75	0.14
4588 Cr II	0.13	0.31	0.18	0.73	0.11
4030 Mn I		0.48	0.11	0.61	
4045 Fe I	0.20	0.39	0.11	0.53	0.10
4178 Fe II	0.10	0.22	0.15	0.67	0.10
4522 Fe II		0.45		0.62	0.12
4215 Sr II	0.90	0.38		0.98	0.10
4077 Sr II	1.25	0.28		1.34	0.09
4205 Eu II	0.21	0.49		0.65	0.12
4435 Eu II		0.44		0.58	0.07

Table IV gives a comparison of the quantities characterizing the continuous spectrum and the hydrogen spectrum of 73 Dra and the other magnetic stars. We note that the intensities of the Balmer lines are averaged over the whole period, while the Balmer discontinuity and the quantic number n of the last visible Balmer line are relative to the maximum because we do not have spectrograms well exposed in the ultraviolet for the epoch of minimum.

TABLE IV

line	γ Equ	β C Bo	ε U Ma	73 Dra	α^2 C Vn
B-V	0.25(A9)	0.27(A9)	— 0.03(A0)	0.07(A1)	— 0.12(B8)
U-B	0.13	0.14	0.02	0.13	— 0.32
$H\gamma$	21.5	17.6	12	14	10
$H\delta$	15.7	18.6	9	14	10
n			18	22	19
D	0.38	0.34	0.54	0.35	0.335
R_c	0.84	0.87	0.85	0.80	0.77
Sp. type $H\delta$ D	A7 V	A7 V	A0 V	B8 V	B8 IV
Sp. type λ_1 D	A7 V	A7 V	A0 V	B9 Ib	B8 IV

From these data it follows that the color of 73 Dra corresponds to A1-type and the spectral type according to the Hack's classification (7) is or B8 V or A9 IV. According to the color index the first type is more probable, a result which is in great contrast to the results given by the metallic line spectrum, showing that 73 Dra is very similar to γ Equ or β C Bo and definitely more advanced than α^2 C Vn and ε U Ma.

Moreover we note that the quantic number of the last visible Balmer line, n = 22, suggests a luminosity higher than that indicated by the contours of the Balmer lines. 73 Dra was not classified by Chalonge (8); but since a strict correlation exists between the quantic number n and the parameter λ_1 used by Chalonge we find that $\lambda_1 = 3725$. It follows then a λ_1 D spectral type B9 Ib or F5 I. According to the color the first type is the more probable. The disagreement between the classification H_δ D and the classification λ_1 D is the evidence of the different luminosity class indicated by the intensity of H_δ and by the quantic number n.

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ELECTRON DENSITY AND HYDROGEN ABUNDANCE.

The number of neutral hydrogen atoms in the second quantum level is derived by using Minnaert's formula. With $R_c = 0.80$, $R = 0.55$ we find

$$\log N_{02}\, h = 17.10.$$

The electron density is computed using the Inglis and Teller formula; since $n = 22$ it follows that $\log N_e = 13.25$.

From the Holtsmark theory we find

$\log N_e = 14.17$ (Hβ)
$\log N_e = 14.32$ (Hγ)
$\log N_e = 14.29$ (Hδ)

The mean is $\log N_e = 14.26$. This value in one order of magnitude higher than the value given by the Inglis - Teller formula. We have already observed that actually the quantic number of the last visible Balmer line suggests a luminosity higher than that indicated by the contours of the Balmer lines. This fact probably can be explained by the existence of an extended atmosphere in which sharp and deep Balmer lines are formed. The contours of Hγ, Hδ, etc. support this interpretation: a deep and sharp core is visible, surrounded by broad wings (fig. 5) somewhat similar to the Balmer contours of some shell stars (for exemple ζ Tauri, or φ Persei). The lower value of the electron density would be indicative of the density in this extended atmosphere, while the higher value would be indicative of the density in the stellar photosphere. This extended atmosphere can probably explain also the characteristics of the metallic spectrum. A similar discrepancy between the electron densities derived by different methods was found for β C Bo and for γ Equ: the Balmer contours gave a value one order of magnitude higher than the electron density derived by the ionization equilibrium of Fe I and Fe II. These results support the hypothesis of an extended atmosphere surrounding this type of stars. No discrepancy of this kind was found for α^2 C Vn, which has a much weaker metallic line spectrum.

THE CURVE OF GROWTH.

The curve of growth that we constructed is relative to the phases of maximum intensity of the lines (Table V). This curve was constructed using the $\log X_f$ given by Wright (9), or, if missing, were deduced from

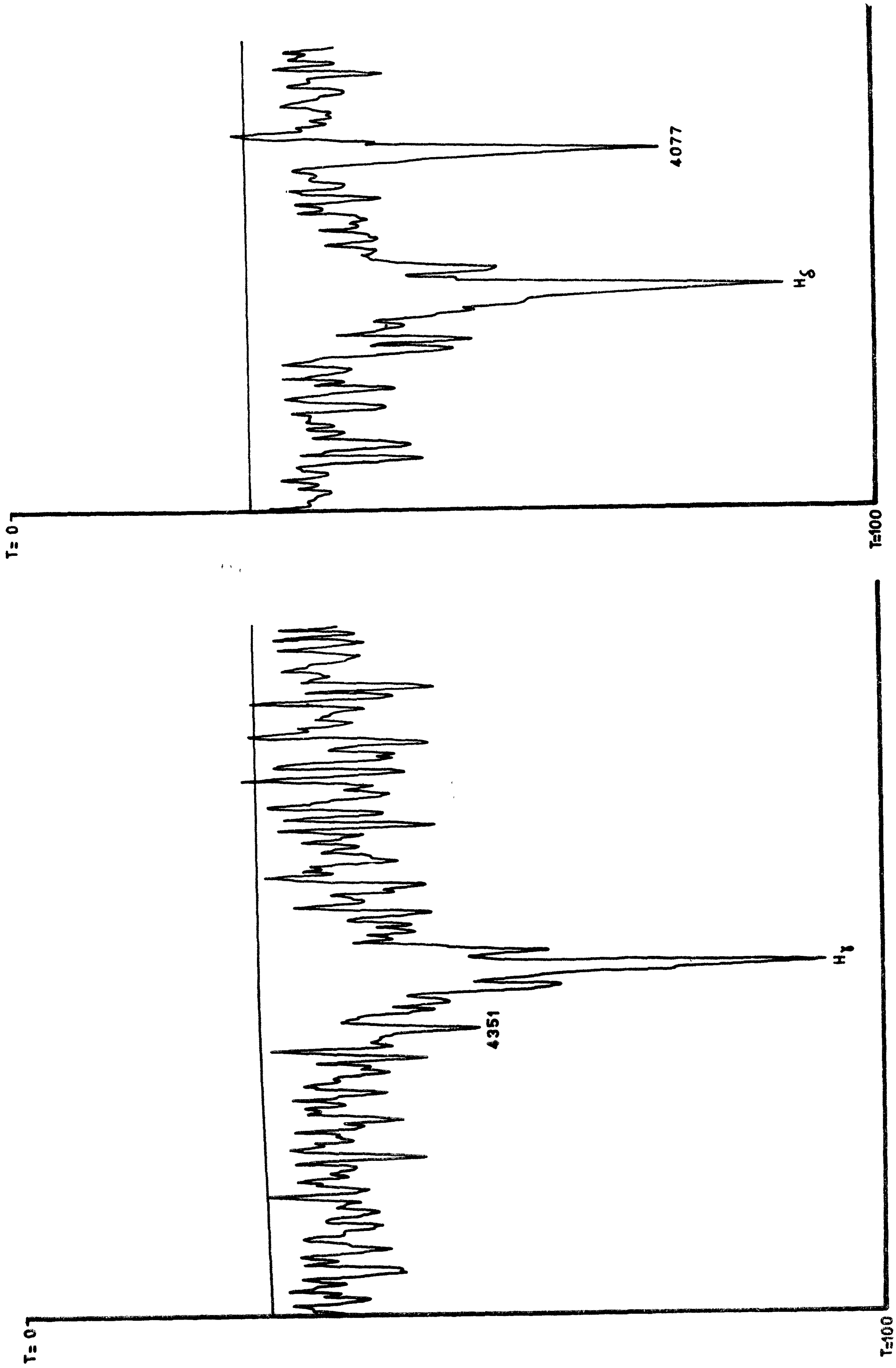

Fig. 5

the catalogue of the Fraunhofer lines of Utrecht (10), using the solar curve of growth constructed by Wright (9).

For the resultant of thermal and turbulence velocities we found (fig. 6):

$$\log \frac{c}{v} = +\, 4\,60 \quad \text{for } Fe\ I$$

$$\log \frac{c}{v} = +\, 4\,50 \quad \text{for } Fe\ II$$

and then respectively

$$v\ (Fe\ \ I) = 7{,}6\ \text{Km/s}$$

$$v\ (Fe\ II) = 9.5\ \text{Km/s}$$

These values are much higher than the corresponding values found for γ Equ (1.5 km/s) and β C Bo (5 km/s), and this explain the greater strength of the lines in the spectra of 73 Dra compared with the other two stars. The determination of the damping branch of the curve of growth is uncertain. The more probable value is $Z = \frac{\gamma}{v}\ \frac{c}{v} = 0.01$, and hence γ is of the order of $10^8\ s^{-1}$: the collisional damping seems therefore to be negligible.

A direct determination of the excitation temperature was very uncertain, since almost all the lines fall on the flat part of the curve of growth. If we divide the Fe I lines in two groups, one with excitation potential between 0 and 1.5 eV, and another with excitation potential between 2.2 and 3.0 eV, we are able to estimate that $\theta_* - \theta_\odot$ is ranging between 0 and -0.3. The curve of growth constructed using $\theta_* - \theta_\odot = 0$ is not appreciably different from the curve constructed using $\theta_* - \theta_\odot = -0.3$.

Assuming $\theta_* - \theta_\odot = 0$ find the following results:

$$Fe\ I\!: \log \frac{X_*}{X_f} = -\,0\,40 \qquad \log \frac{v_*}{v_\odot} = +\,0.56$$

$$Fe\ II\!: \log \frac{X_*}{X_f} = +\,0.66 \qquad \log \frac{v_*}{v_\odot} = +\,0.66$$

Assuming $\log N_e = 13.25$ we determine what the value is for the ionization temperature which satisfies the observed ratio $\log \frac{X_*}{X_f}$ (Fe I) and $\log \frac{X_*}{X_f}$ (Fe II).

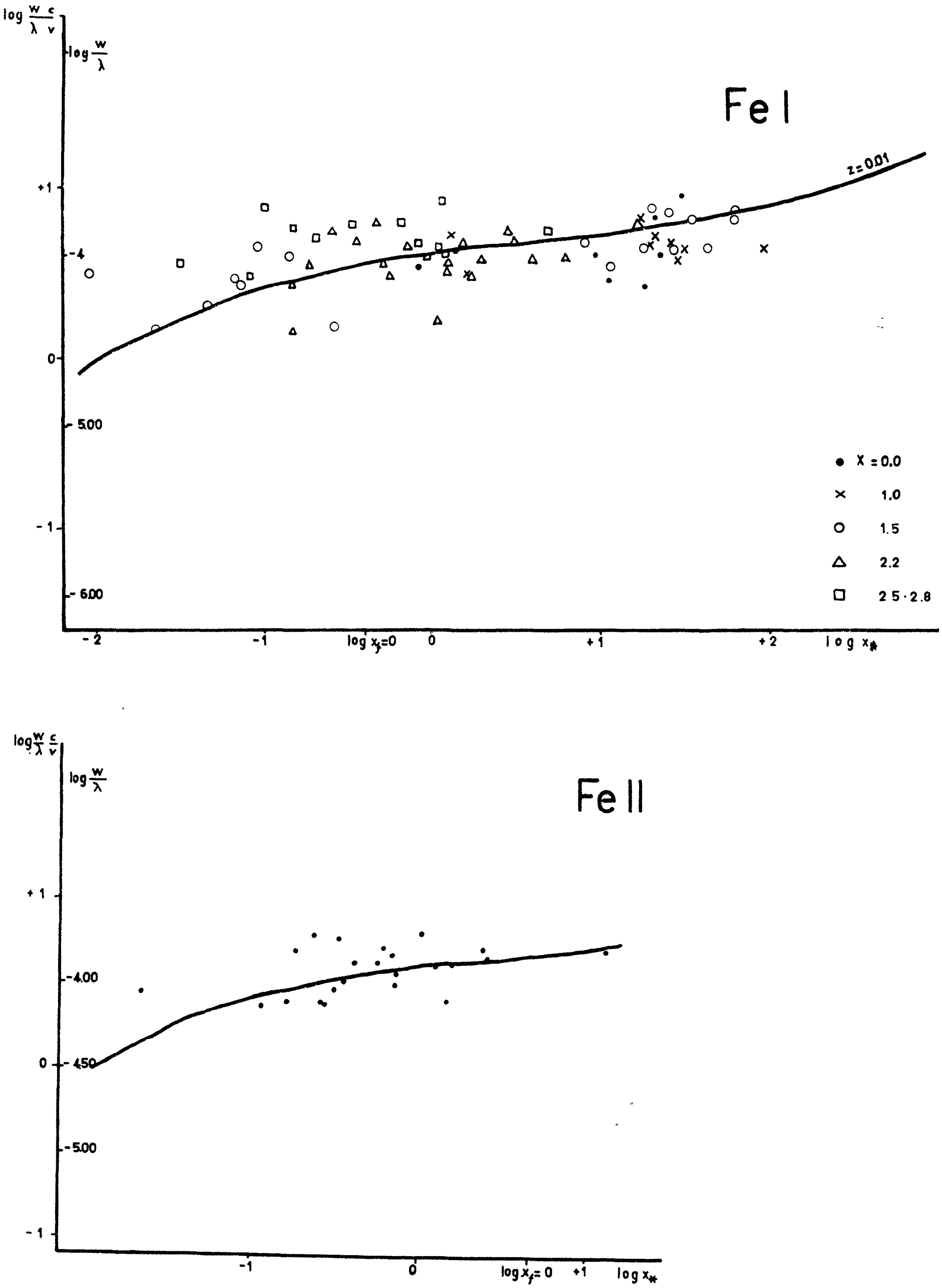
Fe I
log $\frac{W}{\lambda}\frac{c}{v}$
log $\frac{W}{\lambda}$
+1
-4
0
5.00
-1
6.00
z=0.01
• X = 0.0
× 1.0
○ 1.5
△ 2.2
□ 2.5-2.8
-2
-1
log x_f=0
0
+1
+2
log x_*
Fe II
log $\frac{W}{\lambda}\frac{c}{v}$
log $\frac{W}{\lambda}$
+1
-4.00
0
-4.50
-5.00
-1
-1
0
log x_f= 0
+1
log x_*

Fig. 6

TABLE V

Element	mult.	— log (W/λ)	log X_f	log X_*
Mg II				
4481.33	4	3.55	— 1.65	+ 1.70
4481.13	4		— 1.39	
Si II				
3856.02	1	3.76	— 0.20	+ 1.20
3862.59	1	4.01	— 1.40	— 0.60
Ca II				
3933.66	1	3.37	+ 4.25	+ 2.0
Ti II				
4395.03	19	3.93	+ 0.32	— 0.30
4443.80	19	3.81	+ 0.14	+ 0.80
4468.49	31	3.78	+ 0.20	+ 0.80
4501.27	31	3.73	+ 0.07	+ 1.40
3900.55	34	3.72	+ 0.56	+ 1.40
3913.46	34	3.96	+ 0.53	— 0.40
4417.71	40	3.97	— 0.31	— 0.50
4300.05	41	3.70	+ 0.52	+ 1.50
4290.22	41	3.77	0.00	+ 1.40
4312.86	41	3.96	+ 1.18	— 0.40
4533.97	50	3.75	— 0.44	+ 1.30
4563.76	50	3.77	+ 0.44	+ 1.20
4399.77	51	4.03	— 0.03	— 0.66
3741.63	72	3.95	+ 0.64	— 0.46
3757.68	72	3.83	+ 0.68	+ 0.70
4571.97	82	3.84	+ 0.14	+ 0.60
4163.64	105	4.16	— 0.28	— 1.16
Cr I				
4254.35	1	4.01	+ 1.22	— 0.20
4652.16	21	4.11	— 0.51	— 0.60
4651.28	21	4.31	— 1.31	— 1.30
4600.75	21	4.02	— 0.92	— 0.20
4626.19	21	4.05	— 1.02	— 0.38
4371.28	22	4.07	+ 0.52	— 0.45
4359.63	22	3.97	+ 0.26	+ 0.40
3919.10	23	3.88	+ 0.16	+ 1.10
4526.47	33	3.79	— 1.00	+ 1.40
4530.75	33	3.90	— 0.74	+ 1.00
4540.50	33	3.83	— 1.54	+ 1.40
3963.69	38	4.15	0.00	— 0.76
3983.91	38	3.77	— 0.64	+ 1.35
3991.12	38	3.88	— 0.88	+ 1.10
4698.46	186	3.85	— 1.60	+ 1.30
4663.83	186	4.19	— 1.96	— 0.90
Cr II				
4242.38	31	3.80	— 0.80	+ 0.80
4261.92	31	3.80	— 1.43	+ 0.80

Cont. table V

Element	mult.	— log (W/λ)	log X_f	log X_*
4275.57	31	3.76	— 1.14	+ 1.20
4284.21	31	3.86	— 1.44	+ 0.60
4252.62	31	3.81	— 1.80	+ 0.80
4269.28	31	4.22	— 1.66	— 1.30
4558.66	44	3.71	— 0.98	+ 1.42
4588.22	44	3.75	— 1.28	+ 1.30
4618.83	44	3.90	— 0.92	— 0.16
4634.11	44	3.84	— 1.57	+ 0.14
4616.64	44	3.82	— 1.71	+ 0.80
Mn I				
4033.75	2	3.72	+ 1.08	+ 1.70
4034.49	2	3.88	+ 0.95	+ 1.10
Fe I				
4375.93	2	4.06	+ 0.31	
4427.31	2	3.97	+ 0.52	
4461.65	2	3.85	— 0.20	
3856.91	4	3.77	+ 1.70	
3878.57	4	3.64	+ 1.86	
3895.66	4	4.13	+ 1.44	
3922.91	4	4.18	+ 1.65	
3927.92	4	3.99	+ 1.74	
3920.26	4	3.98	+ 1.36	
3825.88	20	3.96	+ 2.34	
3840.44	20	4.03	+ 1.84	
3849.97	20	3.78	+ 1.66	
3872.50	20	3.94	+ 1.68	
3940.88	20	3.87	+ 0.50	
3917.18	20	4.11	+ 0.60	
3763.79	21	3.96	+ 1.88	
3727.62	21	3.93	+ 1.80	
3743.36	21	3.89	+ 1.70	
4602.94	39	4.43	— 0.18	
4654.50	39	4.27	— 0.96	
4680.30	39	4.10	— 1.64	
4531.15	39	4.00	— 0.46	
4632.91	39	4.42	— 1.22	
4383.55	41	3.96	+ 2.01	
4404.75	41	3.96	+ 1.81	
4415.12	41	3.92	+ 1.30	
4367.91	41	3.96	— 0.66	
4291.47	41	4.18	— 0.74	
4229.52	41	4.14	— 0.78	
4271.76	42	3.75	+ 1.78	
4325.76	42	3.71	+ 1.69	
4202.79	42	3.91	+ 1.32	
4147.67	42	4.10	+ 0.11	
4045.81	43	3.78	+ 2.18	
4063.60	43	3.78	+ 1.92	
4005.25	43	3.80	+ 1.48	

Cont. table V

Element	mult.	— log (W/λ)	log X_t	log X_*
4143.87	43	4.06	+ 1.45	
3815.84	45	3.73	+ 2.17	
3841.05	45	3.95	+ 1.64	
3902.95	45	4.18	+ 2.79	
4528.62	68	4.01	+ 0.99	
4494.57	68	3.93	+ 0.58	
4459.12	68	3.84	— 0.20	
4442.34	68	4.12	+ 0.63	
4447.72	68	4.05	+ 0.47	
4407.71	68	4.06	— 0.36	
4408.42	68	4.12	+ 0.12	
4430.62	68	3.92	— 0.06	
4282.41	71	4.10	+ 0.48	
4352.74	71	3.80	+ 0.05	
4001.67	72	4.18	— 0.42	
3949.95	72	3.95	+ 0.24	
4009.71	72	4.44	— 0.42	
3852.57	73	4.38	+ 0.41	
3807.53	73	4.12	+ 0.89	
4058.77	120	3.78	— 0.88	
4260.48	152	3.82	+ 1.60	
4235.94	152	4.01	+ 1.18	
4222.22	152	4.01	+ 0.69	
4210.35	152	4.05	+ 0.10	
4198.31	152	3.70	+ 0.28	
4191.44	152	3.85	+ 0.84	
3785.95	177	4.00	+ 0.50	
4067.27	217	3.83	— 0.44	
3997.39	278	3.92	+ 0.30	
3952.61	278	3.66	+ 0.44	
3981.77	278	3.93	+ 0.24	
3945.12	280	4.00	+ 0.46	
3907.94	280	3.89	— 0.30	
4466.55	350	3.98	+ 0.35	
4476.02	350	3.80	+ 0.20	
4443.18	350	3.81	— 0.76	
4454.38	350	3.85	— 0.80	
4401.45	350	4.21	— 1.14	
4181.76	351	3.89	+ 0.38	
4175.64	351	4.03	— 0.22	
4156.80	351	4.00	+ 0.14	
4125.88	351	3.94	— 0.84	
4107.49	351	4.15	+ 0.24	
4207.13	352	3.93	— 0.60	
4184.89	355	3.82	— 0.10	
4173.32	355	3.87	— 0.80	
4213.65	355	4.04	— 0.35	
4134.68	357	3.94	+ 0.24	
4085.01	358	3.86	— 0.24	
3947.53	361	3.79	+ 0.46	
3944.75	361	3.88	— 0.56	

Cont. table V

Element	mult.	— log (W / λ)	log X_f	log X_*
3935.81	362	3.69	+ 1.04	
3925.65	364	3.96	+ 0.26	
4647.44	409	3.90	— 0.65	
4309.38	414	3.81	+ 0.30	
4464.77	472	3.74	— 1.22	
4517.53	472	4.04	— 1.10	
4637.51	554	4.12	— 0.70	
4227.43	693	3.86	+ 1.06	
4247.43	693	3.95	+ 0.43	
4238.82	693	3.88	— 0.34	
4154.81	694	3.86	+ 0.08	
4137.00	726	3.82	— 0.30	
4547.85	755	4.12	— 0.90	
4219.36	800	4.08	— 0.48	
4118.55	801	3.77	+ 0.46	
4596.06	820	4.11	— 1.24	
4673.17	820	3.98	— 1.10	
4643.47	820	4.12	— 1.22	
4690.15	820	4.10	— 1.44	
4678.85	821	4.11	— 0.62	
4667.46	822	3.80	— 1.82	
4525.14	826	3.77	— 0.30	
4611.28	826	4.12	— 0.50	
4484.23	828	4.03	— 0.80	
4479.61	828	4.15	— 1.22	
4401.29	828	4.22	— 0.50	
4388.41	830	4.21	— 0.44	
4433.22	830	4.02	— 0.52	
4469.38	830	3.97	— 0.38	
Fe II				
3938.29	3	3.79	+ 0.46	
3783.35	14	4.10	— 0.48	
4303.16	27	3.89	— 0.45	
4385.38	27	3.89	— 0.55	
4178.85	28	3.69	— 0.63	
4296.57	28	3.95	— 0.79	
4369.40	28	3.99	— 1.78	
4122.64	28	3.74	— 1.14	
4258.15	28	4.03	— 1.16	
4515.34	37	3.78	— 0.87	
4491.40	37	3.87	— 1.04	
4520.22	37	3.87	— 0.90	
4582.83	37	4.09	— 1.62	
4534.17	37	3.79	— 1.38	
4583.83	38	3.84	— 0.22	
4522.63	38	3.79	— 0.26	
4508.28	38	3.83	— 0.81	
4541.52	38	4.13	— 1.58	
3759.46	154	3.71	— 1.28	
4635.32	186	4.05	— 2.30	

Cont. table V

Element	mult.	— log (W/λ)	log X_f	log X_*
Sr II				
4077.71	1	3.32	+ 1.26	+ 2.04
4215.52	1	3.52	+ 1.08	+ 1.80
Eu II				
4205.05	1	3.70	— 1.60	+ 1.48
Ce II				
4186.60	1	4.02	— 0.50	— 0.60
4562.36	1	3.88	— 2.18	0.00
4418.78	2	4.04	— 2.18	— 0.70
4133.80	4	4.05	— 1.97	— 0.75
4165.61	10	4.02	— 1.40	— 0.60
3999.24	57	4.06	— 2.14	— 0.80
Gd II				
4280.49	15	3.91	— 2.25	— 0.20
4327.12	15	4.18	— 2.48	— 1.20

TABLE VI

element	$\log \frac{Nh_*}{Nh_\odot}$	$\log \frac{Nh_*}{Nh_\odot}$ (total)	$\log \frac{N_*}{N_\odot}$
Mg II (1)	+ 3.16	+ 3.16	+ 2.66
Si II (2)	+ 1.21	+ 1.21	+ 0.71
Ca II (1)	— 1.59	— 1.59	— 2.09
Ti II (17)	+ 0.76	+ 0.76	+ 0.26
Cr I (16)	+ 0.76	+ 1.51	+ 1.01
Cr II (11)	+ 2.26	+ 2.26	+ 1.76
Mn I (2)	+ 0.94	+ 2.02	+ 1.52
Fe I (113)	+ 0.04	+ 1.06	+ 0.56
Fe II (26)	+ 1.12	+ 1.12	+ 0.62
Sr II (2)	+ 1.41	+ 1.41	+ 0.91
Ce II (6)	+ 1.81	+ 1.81	+ 1.31
Eu II (1)	+ 3.74	+ 3.74	+ 3.24
Gd II (2)	+ 2.33	+ 2.33	+ 1.83

We assume $\log P_{e\odot} = 1.5$, $\theta_{\odot ion} = 0.88$ and we assume that $(\theta_* - \theta_\odot)_{exc} = (\theta_* - \theta_\odot)_{ion}$, $\overline{\chi}_{1,s} = 2{,}5$ eV, $\overline{\chi}_{o,s} = 1{,}5$ eV.
We find $\theta_* = 0.80$, $\log P_{e*} = 1.2$.

The abundances relative to the sun are given in Table VI. For the velocity v_* we used the value found for Fe I for the neutral atoms and for Fe II for the ionized atoms. The numbers in parenthesis in column 1 represent the number of lines used in the determination of the abundances.

Column 2 gives the abundances of the atoms in a given state of ionization and column 3 the total number of atoms of a given element. Column 4 gives the abundances per cubic centimeter, derived by the relation

$$\log \frac{N_*}{N_\odot} = \log \frac{Nh_*}{Nh_\odot} + \log \frac{k_*}{k_\odot}$$

where k_* and $k_\odot$ are the opacities of the stellar and solar atmospheres (11)

TABLE VII

Star: α^2 C Vn		HD 133209	HD 151199	β C Bo	γ Equ	73 Dra	HD 34452
Element		log (N*/N$_\odot$)					
Na					0,98		
Mg	0.4	1.3	1.2	(1.6)	16	460	∾ 100
Al	1.1	2.2					
Si	10	25	1.3	3.4		5	∾ 100
Ca	0.02	0.05	2.6	1.4	4.8	0.01	
Sc	0.7			2.5	0.53		
Ti	2.6	2.6		7.7	1.6	1.8	
V	1.3	3.2		2.5	6.7		
Cr	5.2	9.6	1.8	30	18.6	40	
Mn	16	15	9	(40)	(57)	33	
Fe	2.9	4.3	1.1	7	4.4	4	1
Co				(10.5)	46.8		
Ni	3.0	2.4		1.8	39.5		
Sr	14	16	65	40	387	8	
Y	20				4.1		
Zr	30	38		90	6.8		
Ba	0.9		0.6	4.5	14.7		
La	1020	200		620	186		
Ce	400	230		880	104	20	
Pr	1070	630		535	270		
Nd	250	140		150	200		
Sm	410	270		192	58		
Eu	1910	890	130	1440	419	2000	
Gd	810	320		890	165	670	
Dy	760	460		3800	310		

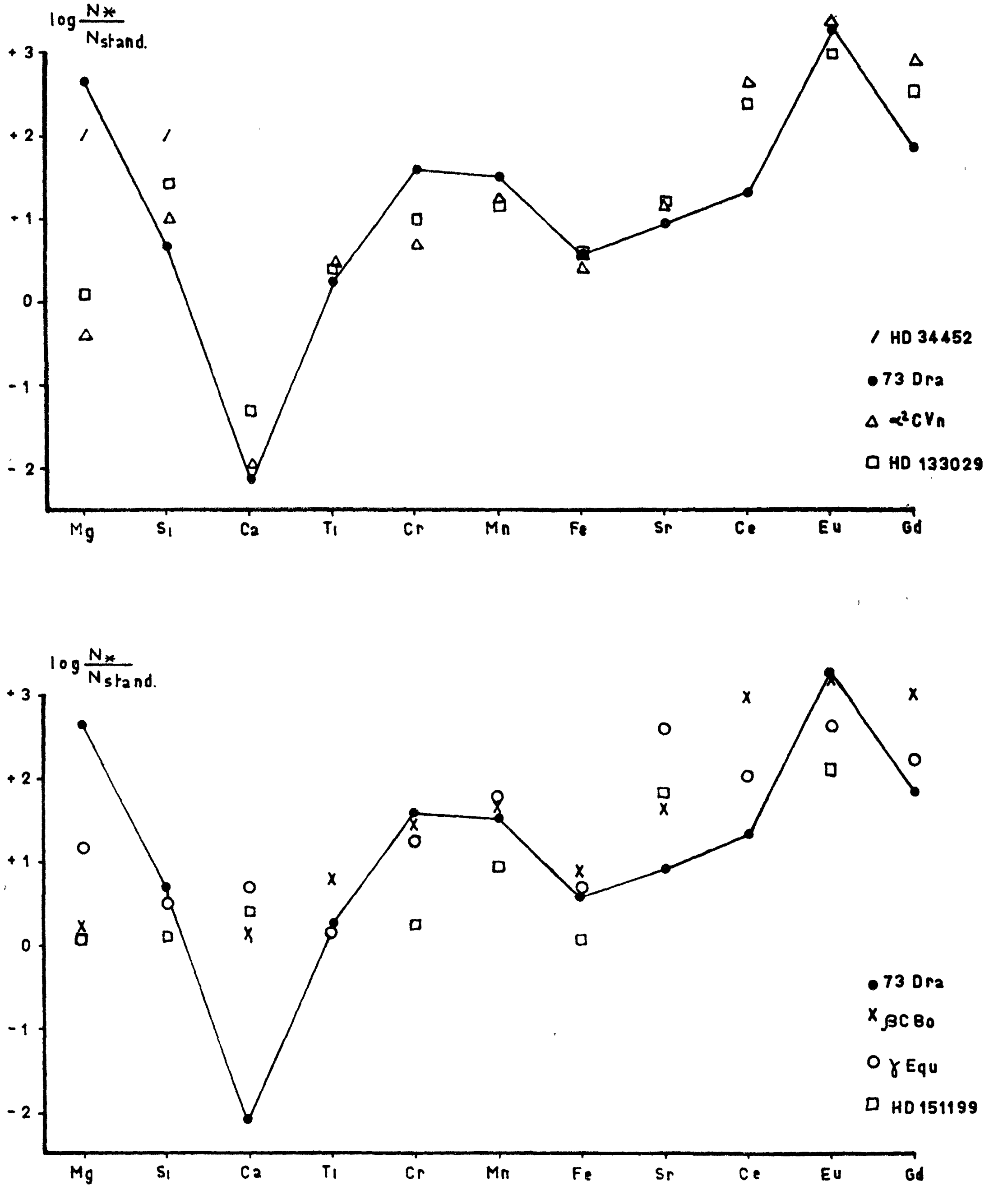

Fig. 7

A comparison of the abundances derived for 73 Dra with those found for the other magnetic stars is given in Table VII and fig. 7. All the 7 stars for which measurements of abundances exist have almost normal abundance of iron and titanium or slightly in excess by a factor of 3. Chromium and manganese are in excess, on the average, by a factor of 10 and 30 respectively. Strontium and the rare earths are constantly in excess by factors which vary appreciably from one star to another. Only for europium we find a remarkable agreement for all the stars (except one) with a factor of the order of 1000. Greater variety of behavior is found among the light elements. For example calcium is underabundant by a factor of 0.01 to 0.05 in 73 Dra, α^2 C Vn and HD 133029 while it is normal in γ Equ, β C Bo and HD 151199. Silicium appears to be constantly in excess in almost all stars by factors ranging from 5 to 100. Magnesium has almost normal abundance in α^2 C Vn, HD 133029 and β C Bo, and is overabundant by a factor of 10 in γ Equ and by a factor of $\sim$ 100 in HD 34452 and 500 in 73 Dra. We note that the determination of the abundances of magnesium and silicium is more affected by the incertitude in the temperature than those of the other elements, because the high value of the excitation potential. Moreover λ 4481 Mg II falls on the damping branch of the curve of growth. The incertitude in our knowlegde of the damping parameter Z can affect the determination of the abundance more than the incertitude in the temperature. However the existence of an excess for magnesium by a factor at least of 50 is certain for 73 Dra, if $Z \leqslant 0.1$.

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