Rev. Mexicana Astron. Astrof. **12**, 163-172 (1986)

AN OBSERVATIONAL STUDY OF THE SI-λ4200 STARS.

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RESUMEN. Mediciones de intensidad e identificacion de lineas en la region espectral azul (3700-4900Å) fueron tomadas para 10 estrellas de tipo Si, como tambien para varias estrellas de tipo standard. Ademas con la ayuda de datos fotometricos pudemios determinar las caractéristicas del grupo y estudiamos el lazo existente con otros grupos de estrellas magneticas, quimicamente peculiares.

ABSTRACT. Intensity measurements and line identifications are presented of the blue spectral region (3700-4900Å) for 10 Si stars and for several standard stars. Combining these observations with available photometric data, the characteristics of the group are studied and linked with the groups of magnetic chemically peculiar stars.

I. INTRODUCTION

Among the classical Ap and Am stars, the Si group was the only one for which as yet no homogenous spectrographic study exists. The need for such a study was stressed recently by Hack(1981). Moreover the connection of the Si group with He stars gives them great importance among the chemical peculiar stars. It is therefore of interest to see if the group can be divided into subgroups, like magnetic He weak stars e.g. Sr,Ti and Si(Borra et al 1983, Jaschek[2] 1974) or if the group is truly homogenous.

As a first step in a detailed study it is necessary to determine the fundamental physical parameters which describe the group. I would like to point out that more details on identifications, or other points of this study are available in my thesis(Didelon 1983b).

II. OBSERVATIONS

For this study I have observed 20 Si stars in the Northern hemisphere and 16 comparison stars taken from luminosity classes III-V. High dispersion spectra(12Å/mm) were obtained at the Haute-Provence Observatory using the coudé spectrograph at the 1.5m telescope, in the wavelength region 3700-4900Å, using baked IIaO plates. The spectra were widened to 0.9mm and the projected slit width was 22µm.

The spectra and corresponding calibration wedges were reduced via a microdensitometer and converted into tracings of relative intensity (I/Ic) and wavelength λ, using a program written by J.Chauville on the Meudon Observatory Vax. The program further measures and lists all equivalent widths Wλ of all lines above a set threshold.

III. IDENTIFICATIONS

For identification purposes I have attributed an intensity(related to depth) to each line on a scale from 0 to 5, where 0 corresponds to a line barely visible above the grain and 5 to the strongest lines. The identification was made in the usual way, using primarily the Revised Multiplet Table (Moore 1945) and the NBS table (Reader & Corliss 1981).

I have selected the Si stars which are of good plate quality and have an interesting spectra, also 5 standard stars, 3 with a relatively cool spectral type(A1-A2), and 2 hotter ones(approximatly B5), which define more or less the borders of the Si-λ4200 group.

Table 1

Identification of Elements in Si and Standard Stars

Nº HD	27396 STD	3369 STD	34452	29009	177410	25823	16545	14392	179527	219749	68351	133029	STANDARDS
Vsini	15	35	50	(40)	(80)	20	(60)	80	35	85	30	<20	<10>
Magn. Field	-	-	p	-	-	H	U	U	U	U	H	H	U
ST_{UBV}	B4.5	B5	B4	B6	B5.5	B6	B6.5	B7.5	B8	B8	B9.5	B8.5	<A1>
ST_H	B4	B5	B6	B4.5	B7.5	B7.5	B8.5	B8.5	B6.5	B8	B8.5	B8.5	
He I	p	p	--	--	--	p?	--	a	--	?	a	--	a
C II	p		n-	--	p?	n-	a	a	n	a	n+	n+	
N II	p		4242?			3995?							
Mg II	p	p	++	--	n+	-	-	--	n+	--	n-	++	p
Al III	p?		?										
Si I			p?	p?	?	p+	p+	?	?	?	p+	p	p
Si II	p	p	++	+	++	+	++	+	+	+	++	++	p
Si III	p	4552?	n+	n-	n+	p	?	a	a	a	?	p	
P II	p?					?					?		
S II	p		?					p?					
Cl II			p			p							
Ca II			++	+	+	n	p	n	n	--	n	n	p
Ti II			p+	p+	p+	p+			+		p	+	p
V II			p+			p+		p		?		?	p
Cr I									p?		p+	+	p
Cr II			+	p+	p+	p+		p	+		++	++	p
Fe I			a	p				p	p	?	p	+	p
Fe II	4233	4233	++	p+	p+	+	p	n+	++	n+	++	++	p
Fe III			p	a	?	a	p?	a	?	a	a	p	
Ga II			?			p			?				
Sr II			?	p?	?	p	?		+		p	p?	p
Eu II			p	?					p		p	p?	
Gd II			?			p?			p		?	p?	
Other Elements	OII		SIII?			ScII	ScII?		BeII?		BeII?	ScII? and heavier elements?	MgI, AlI NiII, YII ZrII, BaII

- Notes to Table I -

n	normal	P	present
n-	normal or slightly weak	P+	present and perhaps enhanced
n+	normal or slightly enhanced	P?	probably present
+	enhanced	?	perhaps present
++	strongly enhanced	a	absent
-	weak		
--	very weak		
STD	standard star		
H	well established magnetic field		
P	magnetic field probably present		
U	unmeasurable magnetic field		
-	no data		

The usual elements are presents in these 5 stars. Intercomparing the standard stars the metal lines are seen to disappear at B8-B9. Only the strong lines, e.g. FeII 4233 remain.

a. Comparison of the identifications

The results of the identifications are listed in Table I with other parameters. The stars are, from left to right; 2 hot standard stars(HD27396,3369), 10 Si stars, and 3 cool standard stars(HD47105,97633,107259) which are similar and so grouped in one column. The Vsini values are taken from Uesugi & Fukuda(1982) when available. Otherwise the value is estimated from Wλ and width at half maximum (Burkhart,1978) and given in brackets. Two spectral types are deduced, one from Wλ of Hγ ST_H, and the other from the Geneva photometry ST_{UBV}, see next paragraph. The possible presence of an effective magnetic field is indicated (Didelon,1983a).

From inspection of the table, it can immediately be seen that Si stars even when hot, show metallic lines typical of cooler standard stars. This suggests an overabundance of these elements (Ti,V,Cr,Fe and even Sr,Eu,Gd). In the same way, when present, lines of ClII,GaII and possibly SII,PII suggest an overabundance.

ClII was discovered for the first time in HD25823,(already known to be present in HD34452)which is the sixth chlorine star discovered(Didelon,1983b). GaII was also identified in this star but MnII was not present. This is in disagreement with the generally accepted abundance correlation of these elements, and then appears to restrict this relation to Hg-Mn stars. Moreover this star has a well established effective magnetic field of 1.3 KiloGauss, which contradicts the consensus that the presence of GaII is more or less a sign of magnetic field absence.

As expected, helium lines are very faint; only the strongest ones(λλ4471,4026,3820) are seen. Silicon is enhanced, both SiI and SiII are seen in all stars, the latter being dominant. The lines of the ionized metals show a variable enhancement from star to star. On the other hand, the intensities of the iron peak elements seem to be correlated. This is very clear for FeII and CrII, slightly less for VII,TiII, and perhaps present for SrII. Due to a lack of numerous lines the identification and the enhancement evaluation can be difficult for TiII, and especially for VII and SrII, then a clear cut affirmation is not possible.

EuII and perhaps GdII seem to be present in the "cool" Si stars where FeII is enhanced. Similarly, ClII and GaII are present in some "hot" stars where FeII is enhanced.

We must note that the silicon intensity is not correlated with any other element intensity. So silicon and the light elements, CII,MgII,CaII and perhaps SII and PII,show an erratic behaviour, without interrelations or correlations with heavier elements.

b. Discussion

Comparison between other identified Si stars(Didelon,1983b) or with He weak stars of relatively cool type (e.g.;HR6000,B6,Andersen et al,1984; 20 Tau,B7,Mon et al,1981), show similar enhancements, more or less pronсовced; on one hand of the silicon lines which characterise the Si group, and on the other hand some enhancement of the iron peak elements(Fe,Cr,Ti,V), and occasionally of others elements such as Eu, Gd and Cl, Ga.

This defines two parameters or characteristics of Si stars. These two characteristics are not correlated but independent, and the differences from star to star are due to an enhancement, more or less pronounced of each group of element. In this scheme we find a natural place for "extreme" stars. For example, in HD16545 silicon is strongly enhanced and the iron

peak elements are normal. In HD168733 (Muthsam & Cowley,1984) we see the reverse, enhancement of the iron peak elements and Si near normal. The latter is certainly linked with the He weak star HR6000, where silicon is underabundant and the iron peak elements strongly enhanced.
The absence of silicon in some stars, at this higher temperature masks one parameter, or there is a breakdown in this parameter relation to the silicon lines intensity.

So the division of magnetic He weak stars into subgroups (Sr,Ti and Si,Borra et all, 1984) seems to be artificial. The classification of these stars is then more difficult and not evident.

This shows that the Si group is homogenous, but can not be described by only one factor two or more independent factors are needed.

IV. SPECTRAL TYPE DETERMINATION FOR Si λ4200 STARS

To compare more accurately the Si stars to normal stars, we must know the temperature or at least the mean spectral type of the Si stars. It is well know that the classical temperature estimates are inadequate for Ap stars. The metallic line enhancement does not allow direct comparison with the MK spectral types. The flux absorption in these lines and the broad absorption features in the visual range (λλ4200,5300,6300;Hack,1981) can affect the colors.

However in a restricted temperature range, from spectral type B8 to A1, the colors which determine the Paschen slope (e.g. B-V,b-y,...) give a good estimative of the temperature (Muthsam & Stepien,1980;Didelon,1983b and references therein). For stars hotter than B8 the colors are too blue and result in an overestimate of the temperature, and for cooler types the temperature is underestimated (Hauck,1975).

The hydrogen lines seem to be normal for the color in Ap stars (Gray & Evans,1973; Jugaku & Sargent,1968;Wolff,1967), illustrating that Ap stars have the same atmospheric structures as normal B stars.

The major part of the Si λ4200 stars studied here, lay in the temperature range where the color could be considered a good estimator of spectral type. A priori, this justifies the use of photometric indices to deduce the spectral types.

The dereddened indices $|U-B|_0$ and $|B-V|_0$ from the Geneva photometry have been calculated, and a spectral type deduced ST_{UBV}, using the calibration given by Cramer (1982).

The Wλ of the Hγ line were used to determine the spectral type ST_H. The calibration Wλ(Hγ) vs spectral type is extracted from Balona & Crampton(1974). The deduced spectral type ST_H, corresponds to the luminosity class V.

Adelman and his collaborators have published spectrophotometric data on a large number of Ap stars. These papers are indicated in the bibliography by a S after the publication year. In comparing the observed distribution fluxes with the theoretical ones of Kurucz (1979), they deduced two temperatures; one corresponding to the Balmer discontinuity, the other to the Paschen continuum slope. Often these two temperature were different. Here the relation temperature vs spectral type given by Schmidt-Kaler (Landolt-Bornstein,1982) has been used to deduce two spectral types; one corresponding to the slope of the Paschen continuum, ST_{PC}; the other corresponding to the Balmer jump ST_{BD}, the latter always being hotter.

The comparison of the different spectral types show that the usual temperature indicators do not give for all the stars a single spectral type(Didelon,1983b). The ST_{PC} underestimate the temperature, while the photometric determination ST_{UBV} and ST_{BD} are well correlated, but a comparison with ST_H show that they overestimate the temperature for the hottest stars. Moreover four stars have an inconsistent ST_H which must be corrected. So, there appears to be no single parameter which gives the temperature uniquely for Si stars. Only by comparison can we deduce a mean spectral type, that is representative of the stellar atmosphere. These mean spectral types are given in Table II.

Note that Si stars are restricted to a narrow temperature range corresponding to spectral type B5.5 to B9.5.

The stars, for which ST_{UBV}, ST_{BD} and ST_H are in close agreement are indicated by a star. A star in brackets indicate that there is a good agreement if we use the "corrected" ST_H, i.e. corresponding to stars of luminosity III. For these stars and the remaining ones, the only way to determine the temperature whithout ambiguity is to perform accurate model calculations taken into account the chemical composition of these stars.

Finally, we see that for 60 to 70% of the Si λ4200 stars, the spectral type is well determined.

Table 2

Mean spectral types of Si λ4200 stars

N° HD	Sp. Type		N° HD	Sp. Type		N° HD	Sp. Type	
14392	B8	*	29009	B6.5	(*)	177410	B6.5	
16545	B7.5		32549	B9.3	*	179527	B8	(*)
18296	B8.5	*	34452	B5.5		184905	B8.3	*
19832	B7	*	68351	B9	*	196178	B6	
22920	B5.5	(*)	124224	B8		205087	B8.5	*
25267	B7.5	*	133029	B8.5	*	219749	B8.5	*
25823	B7		170000	B8.7	*	223640	B7	*
27309	B7.5	*						

V. LINES INTENSITIES IN Si λ4200 STARS

As we know now the mean spectral type of the Si stars, we can compare them accurately to standard stars. I have measured the Wλ of representatives lines of the different elements. I have choosen **primarely**, the lines strong enough to be seen in the major part of the stars, and not blended when possible. For some elements (i.e. VII), it is difficult to found such lines. The standard stars are of luminosity class III to V, and cover the temperature range of the Si λ4200 stars.

The rotational velocity often spreads out the lines which are deformed by the plate granulation. So, for a lot of lines (80%), a mean profile have been drawn and the surface was measured with a planimeter. In the case where the line identification and the blending evaluation have been done, the measured Wλ for Si stars turned out to be the same as for standard stars. For the remaining Si stars only the most interesting and strongest lines have been measured. All these data are available on request or in Didelon (1983b). The comparison of the data obtained from two plates for the standard star HD 123299 shows a good agreement.

a. Comparison of the lines intensities

In a previous study (Didelon, 1982), the published values of Wλ for standard B stars were used to determine the variation of the intensity of the most interesting lines according to the spectral type and the luminosity of the star. This defines sequences of reference for B type stars.

The figures 1 to 4 give the variation of the intensity for the following lines: λλ 4026 HeI, 3856 SiII, 4481 MgII and 4233 FeII. The curves show the sequences of reference for standard stars of both luminosity class III-V. In fact, the hydrogene line broadening is

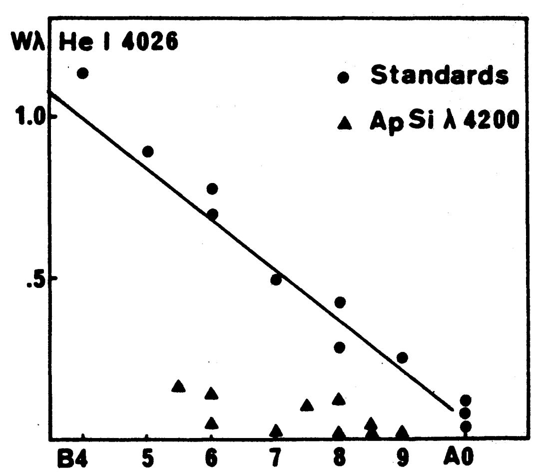

Figure 1. Intensity variation of the HeI line (λ4026) equivalent width given in Å. The curve shows the mean intensity variation of this line for the standard stars of luminosity class III to V (see text). The circles represent the standard stars studied here and the triangles the Si stars.

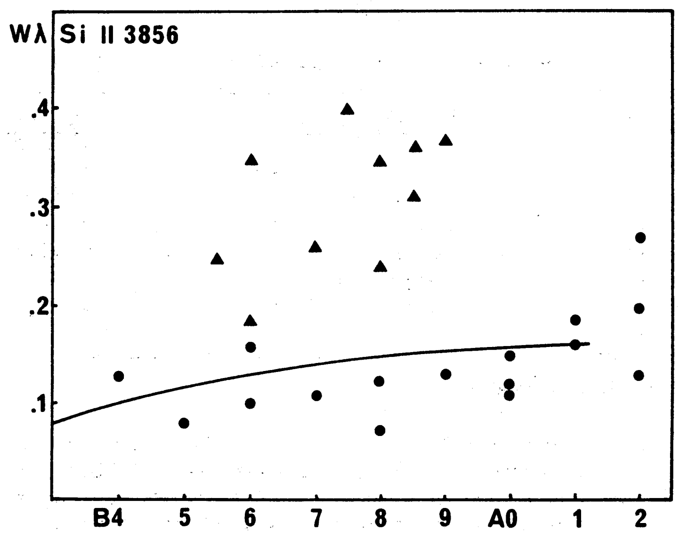

Figure 2. Intensity variation of the SiII line(λ3856) equivalent width given in Å. The symbols have the same signification as in figure 1.

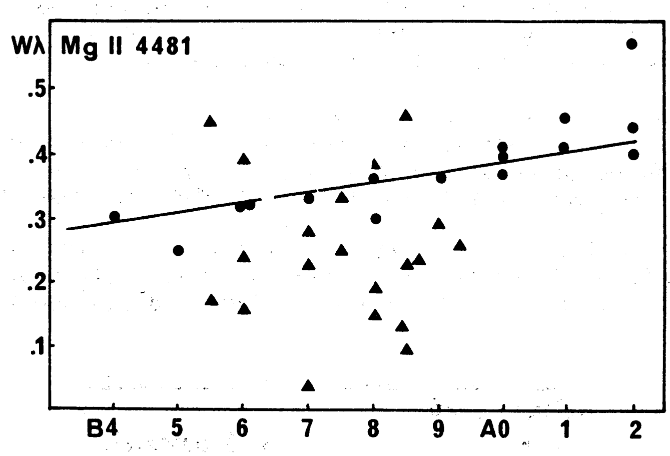

Figure 3. Intensity variation of the MgII line(λ4481) equivalent width given in Å. The symbols have the same signification as in figure 1.

the only luminosity effect visible between class III and V in late B type stars. Therefore a single sequence is valid for class III to V for all the other lines. It is not necessary to take into account the luminosity class I or II, because if Ap stars are not all dwarfs(V), they certainly form part of the class III to V (Didelon 1983b, Floquet 1980).

In the 4 figures the circles give the positions of the standard stars studied here. It can be seen that all the points are situed on or near the curves. The high rotational velocity can explain an underestimation of the line intensities and some blends in cool stars, can lead to an increase of the specious Wλ.

In the same figures the triangles give the positions of the Si stars. In figure 1, we see that HeI line (λ4026) is weak or very weak in Si stars. This HeI underabundance in Ap stars has been known for a long time (Deutsch.1956) and it is simply explained by the radiative diffusion of elements (Vauclair & Vauclair, 1982).

In figure 2 an enhancement of the SiII line(λ3856) appears clearly which means an overabundance of SiII. However we can note that the SiII enhancement is more or less pronounced.

In some stars this line is extremely strong while in some others it is nearly normal or barely enhanced. Therefore, Si stars show a continuous variation of SiII line strength, from normal stars to stars with high silicon overabundance.

The presence of a SiI line in silicon stars of spectral type B, point out an overabundance of this element. (Although the SiIII line (λ4552) seems to be normal or only sligthly enhanced). Alecian & Vauclair (1981) have shown that the strongest the magnetic field of a star is, the most important is the contribution of SiI to the radiative acceleration; at least in the upper atmosphere ($\tau<10^{-3}$) and in regions of horizontal magnetic field. This could explain the enhancement of SiI and we would expect the SiI line strength to be correlated to $|H_{eff}|_{Max}$.

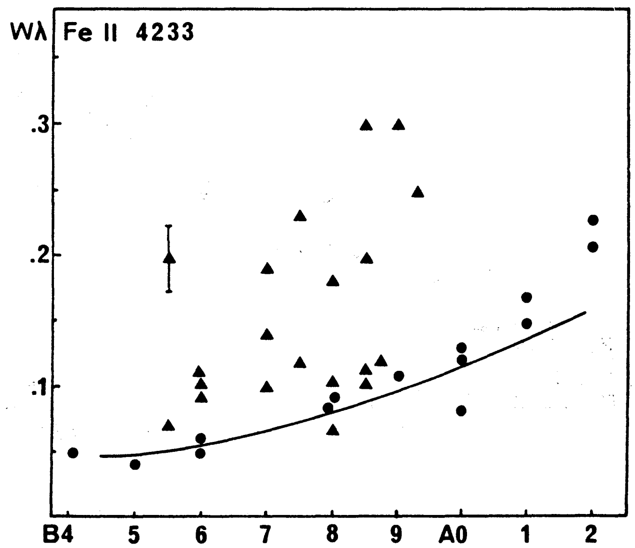

Figure 4. Intensity variation of the FeII line (λ4233) equivalent width given in Å. The symbols have the same signification as in figure 1.

Although the SiI line at 3905Å is located close to an Hydrogene line and sometimes blended with FeII or CrII, the available data seem to indicate such a correlation.

N° HD	14392	34452	25823	133029
Wλ (SiI 3905) in Å	.05	.11	.26	.30
$\|H_{eff}\|_{Max}$ in gauss	125	600	1300	5300

But more data are still needed to confirm this relationship, and to check if there is a saturation at high magnetic field or if we underestimate the magnetic influence. In fact, the field geometry can deeply affect $|H_{eff}|_{Max}$, and surface field measurements (Hs) would be more reliable to reach a conclusion.

The positions of Si stars in figure 3 confirm that the MgII line (λ4481) has an erratic behaviour. It is generally underabundant but appears enhanced in some stars.

The Wλ values of the CII line 4267 seem to show an erratic behaviour too. However it has a tendency to be enhanced in cool stars and to be weak in hot ones. The CaII line (λ3933) show an even more erratic behaviour.

The FeII (λ4233) lines behave like the SiII ones. We have a continuous transition from normal stars to high metallic stars (fig.4). The FeII lines have the tendency to be weaker in hot stars. However, as we know He weak stars which are hotter and show great overabundances of metals (i.e. Fe,Cr,Ti in HR6000), this is certainly due to a selection effect in our sample. However, it would be of interest to study the FeII lines in hot Si stars, to know if HD 34452 is a unique case or if there exists a smooth transition from the high metallic, hot Si stars to the normal ones.

The presence in Si stars of measurable and sometimes strong lines of metals (Ti,V, Cr,Sr), rare earths or exotic element (Cl,Ga) indicate an overabundance of these ones.

b. The correlation of lines intensities

The identifications made in this paper have shown that there is a relationship between the enhancements of FeII and CrII. Figure 5 gives the relationship between CrII λ4558 and FeII λ4233, and we see that their intensities are well correlated. (The same would occur with FeII λ4584). The positions of the stars HD 168733(Hew Sr,Ti,Little & Aller,1970) and 20 Tau(Hew,Mon et all,1981) are given by empty circles. The high rotational velocity of HD 124224 and HD 219749, explains why we can not see their weak CrII lines.

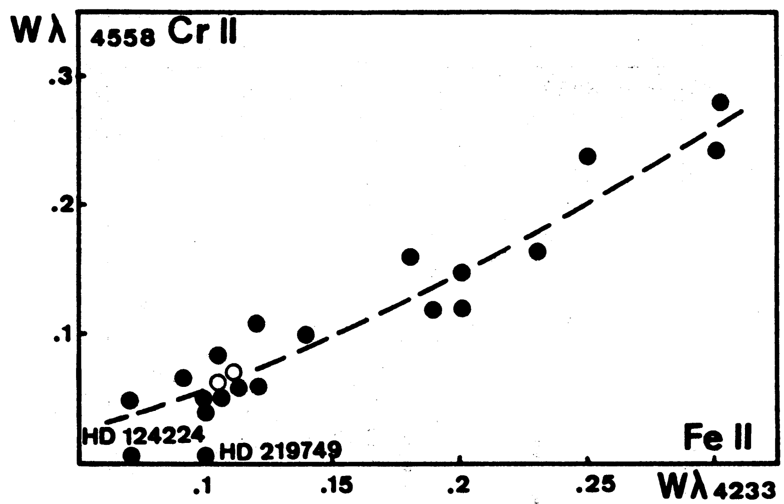

Figure 5. Intensity correlation between the FeII line λ4233 and the CrII line λ4558. The Wλ values are given in Å. The empty circles show the values of HD168733 and 20 Tau, taken from the literature. For the stars with high Vsini (HD124224 and HD219749), the CrII lines are too weak to be measured.

Such a relationship may exist between TiII and FeII or SrII, but the weakness of the lines does not permit to give a definite conclusion. Such a correlation in cooler stars would be worthwile to be investigated.

On the other hand, the line intensities of the light elements(CII,MgII,SiII,CaII) do not seem to be correlated between themselves. Neither are they to the intensities of the metallic lines.

Correlations between line intensity of any element and rotational velocity have been searched. Such a correlation has not been found neither with the SiII intensities nor with the CaII and CII ones, while it may exist with TiII. However, a strong anticorrelation appears between the intensities of the FeII,CrII and SrII lines and Vsini.

The variation of the intensity of the FeII λ4233 line with Vsini is shown in figure 6. Note that the anticorrelation is given by the upper envelope of the points, and the scatter due to the sini factor.

It is generally thought that the metal enhancement increases with age. As the magnetic stars(or at least the Si ones), suffer rotational braking during their lifetime on the main sequence, an anticorrelation is expected between the line intensities of elements and the rotational velocity. However, the previous observations of Ap star braking on main sequence (Abt 1979,Wolff 1981,Borra 1981) are now contradicted by the work of North(1984). This author found that Si stars loose most of their angular momentum before the main sequence phase, as it was previously known for Ap stars of later type. Furthermore, theoretical computations made by Megessier(1984) seem to confirm that the peculiarities of the Ap stars may vary or even disappear during their lifetime.

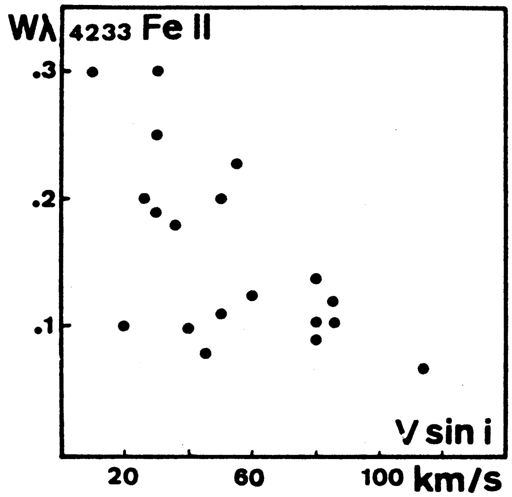

Figure 6. Intensity variation of the FeII line λ4233 versus the rotational velocity. The equivalents widths are given in Å.

One possible explanation could be the following one: strong overabundances would be more difficult to form in the fast rotating stars, as they have a less stable atmosphere than the slow rotating ones. The slower the rotational velocity, the stronger should be the overabundances.

If Ap stars are not magnetically decelerated on main sequence, the observed anti-correlation between Vsini and magnetic field strength(Didelon,1984) must be explained the same way. Magnetic fields can only been kept by slow rotators, as the fast ones would destroy them. These two facts (as well as the distribution of the magnetic axis inclination), show that the internal dynamic of the stars plays an important role in the Ap characteristics.

I. CONCLUSION

This study of Si λ4200 stars has shown that the line strengths of light elements CII,MgII,SiII,CaII) have an erratic behaviour and that they are not correlated with any parameter or element abundance. However, the intensity of the SiI lines seems to be correlated with the magnetic field strength, which can be explained by the radiative diffusion of SiI in presence f magnetic field.

The enhancements of the FeII,CrII and perhaps TiII and SrII lines are correlated etween themselves. Moreover several elements are only present when FeII is enhanced: VII,EuII nd GdII in cool stars; ClII and GaII in hot stars. The enhancement of these elements (mainly e,Ti,Cr,Sr) as well as the Si one, varies continuously. A smooth transition is observed between normal stars and stars where these elements are strongly enhanced.

There exists an anticorrelation between Vsini and the line strength of FeII,CrII,SrII nd perhaps TiII, which seems to indicate that the hydrodynamical conditions may prevent the ormation of strong overabundances.

So the Si λ4200 group appears to be homogenous. It must be described by two independent factors: the strength of the silicon line and the strength of the lines of some elements f the iron peak (Fe,Cr,Ti,Sr). The latter is anticorrelated with the rotational velocity while he former may be correlated with the strength of the magnetic field.

The same scheme may apply to the magnetic He weak stars. In fact the Sr,Ti subgroup as a slower mean rotational velocity (55km/s) than the Si subgroup (90km/s). The previous division of the magnetic He weak stars into subgroups is then certainly incorrect.

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