SPECTROPHOTOMETRIC STUDY OF WEAK-LINE AND STRONG-LINE STARS

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RIASSUNTO. — Nel presente lavoro si è compiuta un'analisi spettrofotometrica di alcune stelle a righe forti e a righe deboli (st-l, wk-l) studiate da Roman e distinte in base a criteri qualitativi. Si è constatato che tale analisi dà dei risultati discordanti da stella a stella; inoltre né l'intensità delle righe, né quella della banda del *CH*, sono criteri sicuri in tutti i casi, per distinguere le stelle dei due gruppi, nelle classi spettrali considerate. Non sono stati trovati effetti spettroscopici notevoli, neppure in stelle aventi velocità spaziali molto diverse. Si sono confrontati i dati spettroscopici con quelli del sistema fotometrico in sette colori, dell'Osservatorio di Ginevra. In base ai risultati ottenuti, sembra probabile che le stelle wk-l, st-l della Roman si distinguano per una diversa abbondanza dei metalli; tuttavia le differenze di composizione chimica sarebbero così piccole da non poter sempre essere rilevate con sicurezza coi metodi spettroscopici. Inoltre molte stelle sono state probabilmente classificate wk o st dalla Roman in modo erroneo. Si conclude che forse sarebbe meglio abbandonare la vecchia distinzione della Roman e considerare invece il parametro di metallicità di una fotometria in sette colori.

SUMMARY. — In this work we have performed a spectrophotometric analysis of some stars studied by Roman and distinguished in strong-line (st-l) and weak-line (wk-l) stars according to qualitative criteria. It has been found that such analysis gives results in disagreement from star to star; moreover neither the intensity of the lines, nor that of CH, can be considered criteria sure in all the cases to distinguish the stars of the two groups, for the studied spectral types. Also stars with very different space velocities do not show noticeable spectroscopic effects. We have compared the spectroscopic measures with those of the photometric system in seven colours of the Observatory of Geneva. According to the obtained results, it seems probable that the wk-l and st-l stars of Roman can be distinguished by the different abundance of the metals; however the differences of chemical composition are so small that, not always, they can be remarked certainly with spectrographic methods. Moreover we believe that probably many stars have been erroneously classified wk-l or st-l by Roman. The following conclusions can be drawn: probably it would be more suitable to leave the old distinction of Roman of wk-l and st-l stars and to consider the metallicity parameter of a photometric system in seven colours.

(*) Ricevuta il 4 Giugno 1970. Testo definitivo il 3 Dicembre 1970.

1. - Introduction

In the present work we examine some stars of spectral type F6-G0, classified by Roman (1950) as weak-line (wk-l) and strong-line (st-l) stars according to a qualitative analysis on spectra having a dispersion of 125 Å/mm. The space velocities of the wk-l stars have a larger dispersion than those of the st-l stars; stars with velocities less than 70 km/sec are found in both groups, those with speeds greater than 70 km/sec only in the wk-l group. Roman suggests this criterion to distinguish st-l and wk-l stars: the ratio of the lines 4340/4325 is noticeably smaller in the wk-l stars, for the same strength of λ 4226.

Studies on wk-l and st-l stars have been performed by means of quantitative methods and spectra with higher dispersion, but the results obtained by the various AA. are in disagreement.

Wellmann (1955; 1957) has observed the couples α CMi – 110 Her, ϑ Dra – HR 7955 concluding that these stars have the same temperature and chemical composition but not the same luminosity.

Pasinetti (1961) has studied three couples of stars having low and similar space velocities; the lines of the wk-l stars result slightly stronger than those of st-l; probably the little differences of intensity may be explained by an incorrect classification of the spectral type or luminosity class.

Spite (1966) points out that Miss Roman's wk-l and st-l stars cannot be distinguished either by abundance or by luminosity.

Considering that many stars of Roman's list have been measured in the photometric system in seven colours of the Observatory of Geneva, we have observed some stars reported in both catalogues; the purpose of this research is to compare the spectrographic results with those photometric, to verify the hypotheses of Wellmman and Pasinetti and eventually to find spectrographic criteria more sure than those suggested by the various AA., to distinguish the stars of the two groups. Moreover we have considered in the observed groups also stars having space velocities very different, to verify the eventual correlation between the velocity and the observed spectrographic peculiarities.

2. - Observations

The spectra, having a dispersion of 35 Å/mm at H_γ, have been obtained with the Zeiss spectrograph of the Observatory of Merate.

The data regarding the observations and the stars examined, are reported in the Table I; the columns have the following meaning: 1), 2) number of the star in *HD* catalogue and name; 3) number in the catalogue of the stars measured in the photometric system of the Observatory of Geneva (Rufener 1970); these stars are also reported by Rufener et al., 1964; 4), 5), 6), respectively spectral

TABLE I

HD	Star	n. Cat. Geneva	Sp. T.	Speed km/sec	Lines	n. sp. - Date
141004	λ Ser		G0 V	50	wk	2686 (5/7/68); 2745 (14/6/69).
114710	β Com	902	G0 V	52	st	2744 (13/6/69); 2750 (26/6/69); 2756 (27/6/69).
4614	η Cas	34	G0 V	27	wk	2697 (19/11/68); 2699 (28/11/68).
95128	47 U Ma	748	G0 V	21	st	2710 (21/1/69); 2726 (30/1/69); 2743 (13/6/69).
126660	ϑ Boo	939	F6 IV	33	wk	2746 (14/6/69); 2747 (25/6/69); 2748 (26/6/69); 2759 (27/6/69).
142860	γ Ser	1002	F6 IV	100	wk	2751 (26/6/69); 2752 (26/6/69); 2757 (27/6/69); 2758 (27/6/69).
163989	35 Dra		F6 IV	19	st	2749 (25/6/69); 2753 (26/6/69); 2754 (27/6/69); 2755 (27/6/69).

type and luminosity class, velocity, characteristic of the lines according to ROMAN (1950); 7) number of the spectrum and date of our observations.

We have used Kodak Plates Ia-0, calibrated with the step sensitometer of the Merate Observatory. The characteristic curves have been determined in the four wavelengths, λλ 3800, 4200, 4400, 4700; these curves were so nearly alike that only one mean curve has been used. The spectra were taken with such times of exposition that the densities correspond to the rectilinear part of the curve. We remark also that the characteristic curves of the different plates are about parallel. The continuum has been plotted taking in account the same points of maximum density for all the spectra. With these precautions the average of the mean errors of the measures is ± 0.02, corresponding to 4-5% (for 35 Dra these values are respectively ± 0.01, 3%). Therefore it has been possible to perform an accurate relative comparison between the stars of the same group.

3. - Results

In the first two groups we have considered stars of the same spectral type and luminosity class. The velocities of the stars of the same couple are very similar; moreover all the velocities are rather low so that it is possible to compare the two wk-l and two st-l stars for a control of the spectral types and luminosity classes. The third group contains stars with very different space velocities: for the wk-l, 19 and 100 km/sec.

In Table II we report the equivalent widths of H_γ, the central depths of 4226 Ca I, the ratios (of the central depths) 4340/4325. These values are used for the control of the criteria of classification according to Roman.

Table II

Name	H_γ	R_c 4226	4340/4325
λ Ser	3.67	0.75	1.11
β Com	3.78	0.78	1.57
η Cas	4.31	0.67	1.28
47 U Ma	3.69	0.76	1.11
ϑ Boo	4.13	0.65	1.73
γ Ser	4.31	0.64	1.62
35 Dra	4.04	0.64	1.59

The comparison of the intensities of H_γ has been made considering all the spectral region near H_γ reported in Fig. 3(a)-(d) together with the spectral region of the G band discussed later. The profiles are about equal in the cores and the wings save in η Cas and 47 U Ma which show greater differences.

The intensities of H_γ and Ca I λ4226 confirm the equality of spectral type for the stars of the same group; on the contrary, the differences found in η Cas and 47 U Ma would confirm the hypothesis advanced later, of a difference in their classification.

If the criterion 4340/4325 is applied, we find values not always in agreement with the results of Roman. In the first group (λ Ser — β Com) the ratio is less in wk-l star, the contrary happens in the couple η Cas — 47 U Ma. Moreover we note that λ Ser wk-l and 47 U Ma st-l both G0 V, have the same value, 1.11. In the third group, this ratio is about equal (within the errors) for γ Ser and 35 Dra, but it is higher in ϑ Boo wk-l; we note that γ Ser has the highest velocity and therefore the differences could be eventually greater for this star.

Therefore we conclude that the ratio 4340/4325 is not a good criterion to distinguish the wk-l and st-l stars, also if they have the same intensity of 4226. The case of η Cas and 47 U Ma will be again discussed later.

In Fig. 1(a)-(d) we have compared the weighted averages of the central depths of various couples; the values of the wk-l star are reported in ordinates, those of st-l in abscissae.

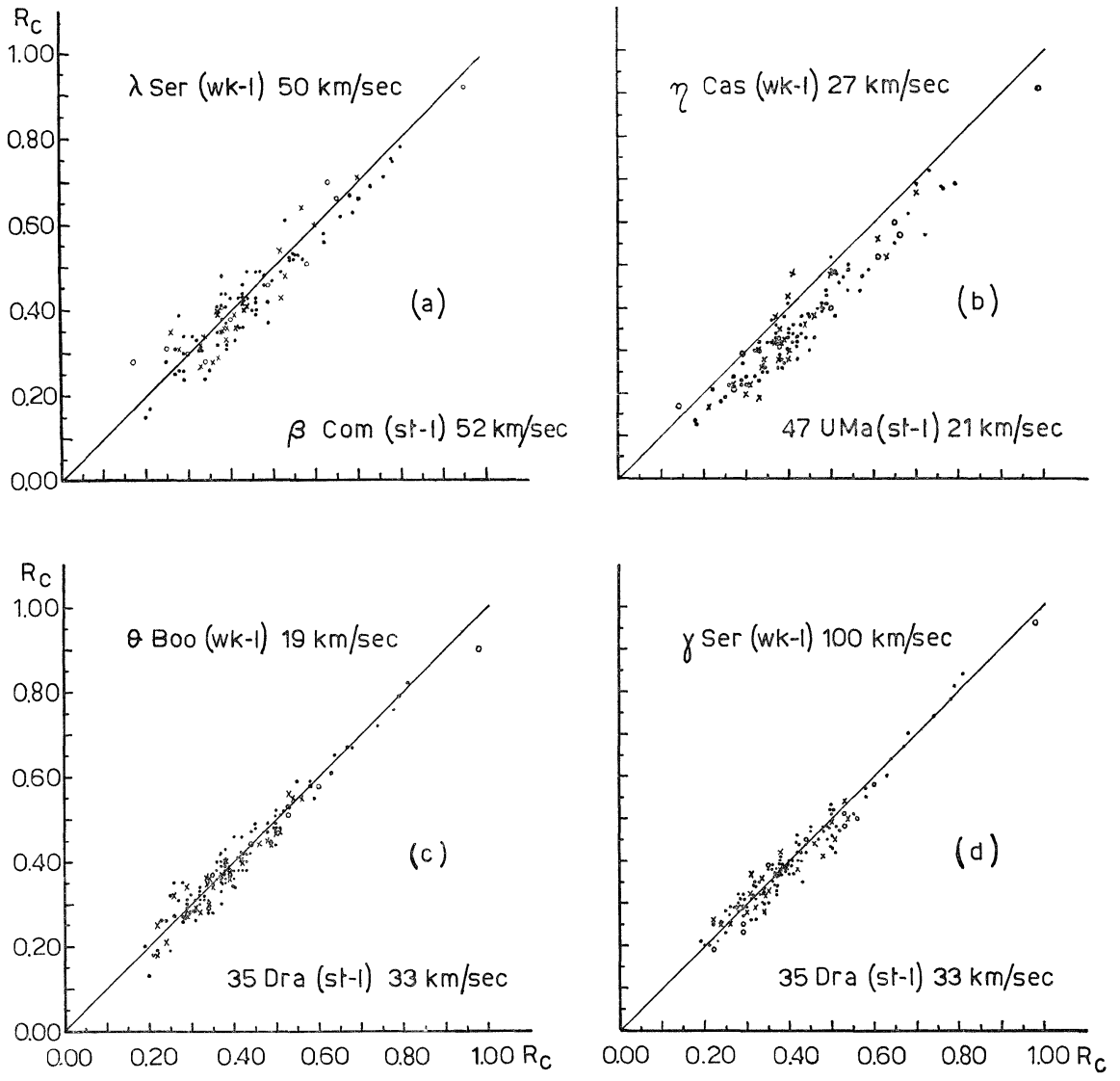

FIG. 1

(a)-(d) - Comparison between the wk-l star (in ordinates) and st-l star (in abscissae), of the same spectral type and luminosity class, ● neutral atoms; o ionized; x blend.

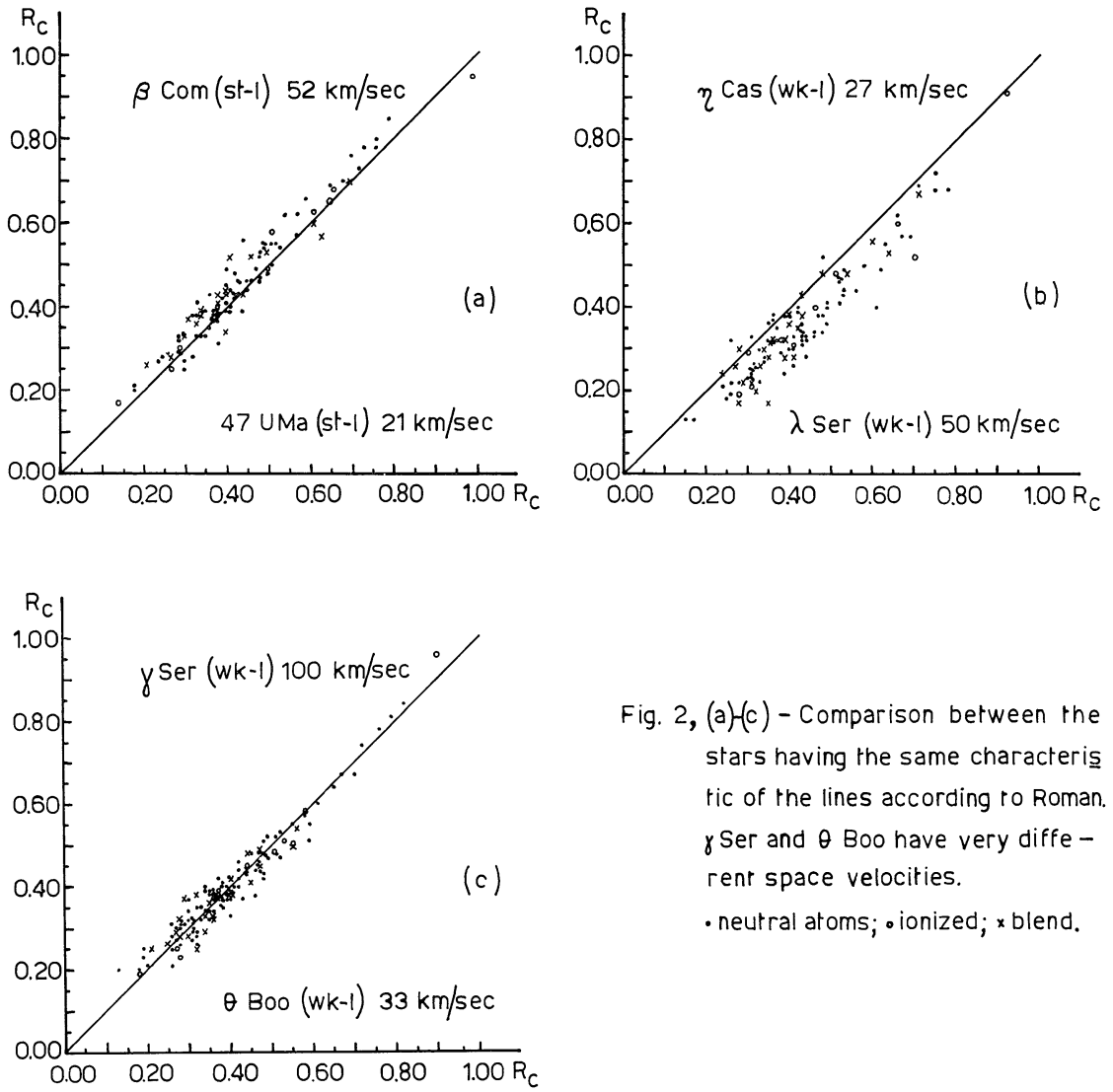

Fig. 2, (a)-(c) - Comparison between the stars having the same characteristic of the lines according to Roman. γ Ser and θ Boo have very different space velocities.
• neutral atoms; ∘ ionized; × blend.

λ *Ser* — β *Com.* - Fig. 1(a) shows very small differences of the intensities; but if we compare the central depths of β Com st-l, with those of 47 U Ma st-l (Fig. 2(a)), we can verify that the lines of β Com show again a stronger intensity; this difference is also slightly greater than in the comparison with the wk-l star. Therefore we can conclude that no difference is observed between the wk-l and st-l star of this group. According to HELFER et al. (1963) β Com would have abundances similar to the Sun.

η *Cas — 47 U Ma.* - η Cas has nearly all the lines weaker than those of 47 U Ma (Fig. 1(b)). Because 47 U Ma is normal (Fig. 2(a)), this result is certainly due to the weakness of η Cas as also Fig. 2(b) shows.

We note that the difference of the ratio 4340/4325 must be the strongest in this case, if the criterion of Roman would be correct.

If the above mentioned differences in the intensities of H_γ and 4226 are taken in account, one could support the hypothesis of an incorrect classification of η Cas, as in the conclusions of PASINETTI (1961); however in that study the wk-l star had the stronger lines.

ϑ Boo — 35 Dra, γ Ser — 35 Dra. - Figg. 1(c), 1(d) show the same result of the first group; moreover no differences could be ascertained between the two wk-l stars of high and low velocity, as it is evident in Fig. 2(c).

We remark that SPITE (1967) has found in γ Ser abundances rather similar to those of the Sun.

We have considered in detail the characteristic region of the *G* band, reported in the figures with that of H_γ. In Fig. 3(a)-(d) the mean curve of the st-l star is plotted with that of the wk-l star.

β Com — λ Ser have nearly the same intensities in the maximum of *CH* at λ 4324, but the st-l star is weaker at λ 4311. This result agrees with those found by WELLMANN (1950) and by HACK (1957). However we have compared β Com and 47 U Ma, both st-l and G0 V, and we have noted that *CH* is considerably weaker (at λλ 4311, 4324) in β Com than in 47 U Ma (see Fig. 4); therefore the result above mentioned is not due to the difference between a st-l and a wk-l star.

When we consider the other groups, we find different results: *CH* stronger in st-l star, at λ 4311 and 4324, in the couple 47 U Ma — η Cas. *CH* slightly stronger at λ 4324 in st-l and nearly equal at λ 4311, in 35 Dra — ϑ Boo and 35 Dra — γ Ser.

Also WELLMANN in a successive work (1952) and PASINETTI (1961) in three groups of stars had found the band of *CH* nearly equal in the st-l and wk-l star.

Furthermore if one considers the couples of stars, both wk-l or st-l, differences of *CH* intensity of the same amount as in the group wk-st, may be found (Fig. 4).

HACK (1957), considering only a couple of stars, has suggested that the criterion which characterizes the two classes, wk-l and st-l, is the larger strength of the *CH* features in the wk-l star. It must be emphasized that just in the couple η Cas — 47 U Ma, in which our results really agree with those of Roman and the difference between st- and wk-l star is considerable, the *CH* is stronger in st-l star, in disagreement with the hypothesis of Hack. Therefore, according to the above mentioned results it seems that such a criterion cannot be considered applicable, at least for the examined spectral types and for the used dispersions (Wellmann 8 Å/mm).

SCHWARZSCHILD (1950) has found the *CH* features somewhat stronger in the high-velocity dwarfs than in the low-velocity dwarfs, and an extremely uncertain difference in the equivalent widths of the Fe I lines. Also in the couple

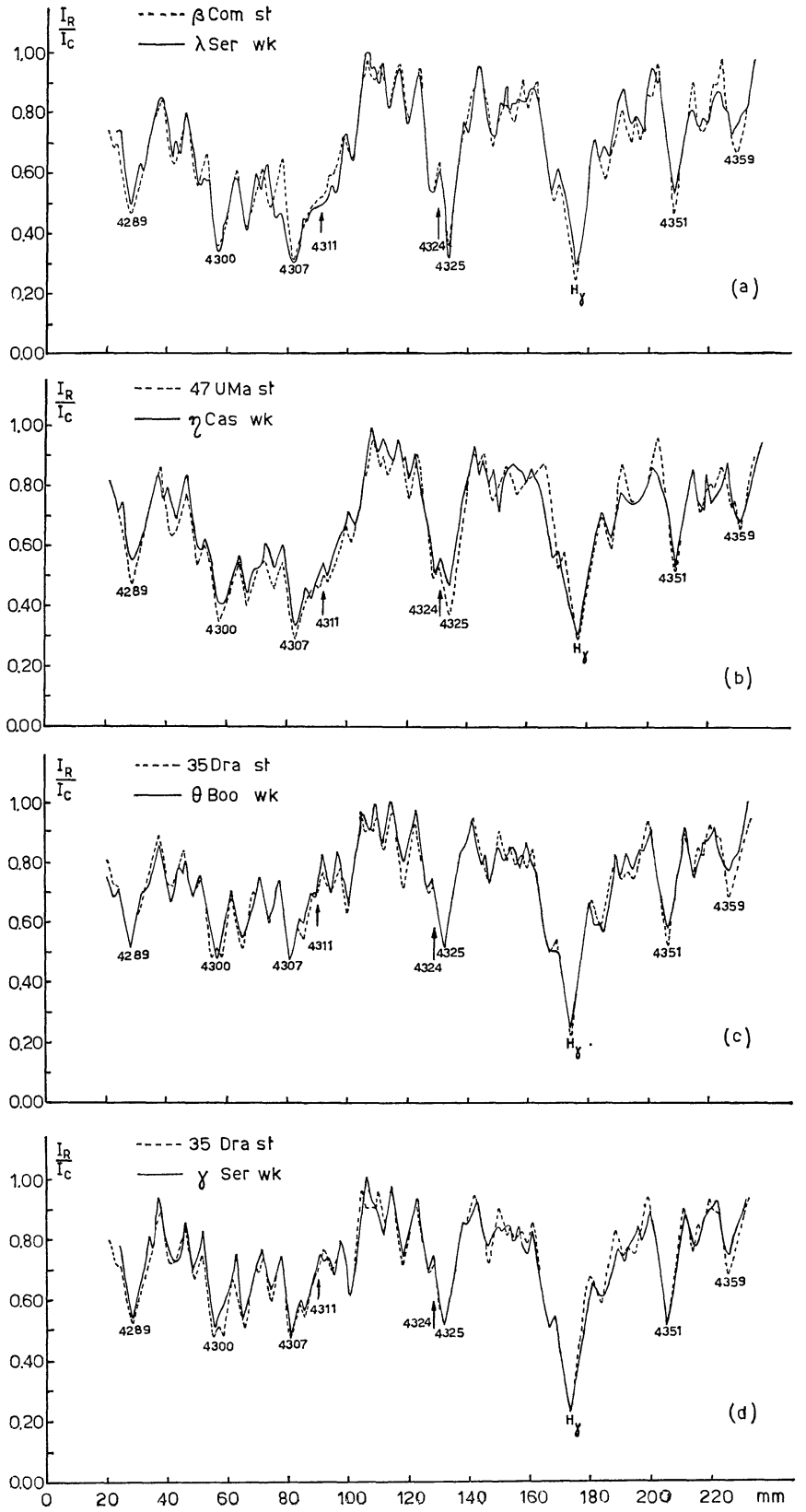

FIG. 3

(a)-(d) - Mean curves of the intensities in the spectral region of G band and of H_γ —— wk-l star; ---- st-l star.

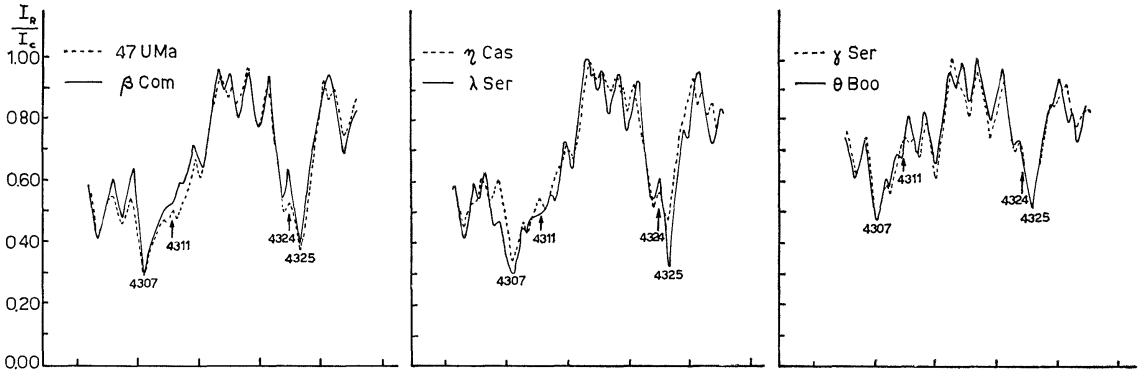

FIG. 4

Comparison of the intensities of *G* band between stars having the same classification.

35 Dra — γ Ser, which are very different in the space velocities, we have not found differences in the *CH* intensity for wk-l and st-l star.

The above mentioned arguments support these conclusions: the spectrophotometric analysis, at least that obtained by spectra of mean dispersion, gives results in disagreement from star to star; moreover neither the intensity of the spectral lines, nor that of *CH*, can be considered criteria sure in all the cases to distinguish the stars of the two groups, for the studied spectral types (F6-G0).

It is very interesting to compare the spectrographic results, with those of the photometric measures in seven colours. We have verified the spectral types and the luminosity classes to confirm or to exclude eventual errors of classification; then the degree of metallicity of the observed stars has been considered.

In the catalogue of Geneva (RUFENER 1970), we have not found λ Ser and 35 Dra. In Table III the data of the observed stars are reported, kindly given to us by Dr. Hauck (private communication).

TABLE III

Name	$B_2 - V_1$	d	Δd	M_v	m_2	Δm_2
β Com	0.332	0.675	0.014	4.42	−0.504	−0.036
η Cas	0.336	0.655	−0.001	4.69	−0.536	−0.069
47 U Ma	0.364	0.629	0.011	4.77	−0.487	−0.033
ϑ Boo	0.263	0.809	0.052	3.36	−0.526	−0.030
γ Ser	0.258	0.822	0.058	3.25	−0.555	−0.056

For the meaning of the parameters and their precision, see HAUCK 1968. Here we remember briefly that: the colour index $B_2 - V_1$ is utilized as parameter of temperature; $d = (U - B_1) - 1.6\,(B_1 - B_2)$ is a parameter of luminosity; $\Delta d = d - d_o$ is the difference between the value of d of the examined star and

that corresponding to the reference sequence (Hyades) which approaches as much as possible to Zero Age Main Sequence of Stromgren (HAUCK 1968, pag. 146); M_v = absolute magnitude; $m_2 = (B_1 - B_2) - 0.69\,(B_2 - V_1)$ is a parameter representing the blanketing effect; $\Delta m_2 = m_2$ (star) $- m_2$ (sequence of reference) is an index of the chemical composition (see Figg. II.8, II.11, HAUCK 1968): if Δm_2 is more negative, the degree of metallicity is less.

Considering Table III, the following remarks can be drawn:

I. - β Com, 47 U Ma, η Cas have nearly the same spectral type and luminosity class; in particular the values of η Cas are intermediate between those of the other two stars. 47 U Ma is the latest and could be classified *G1 V* in the system of Geneva. Fig. 2(a) shows that the strongest lines are those of β Com the earliest star of the group. The calibration in $B_2 - V_1$ corresponds to 0.05 mag. for a given spectral type, and for a given value of $B_2 - V_1$ it is of two divisions of the *MK* spectral type (HAUCK 1968). Therefore, within the limits of the calibration and the errors, the classification of Roman is correct; moreover the hypothesis of an error of classification, derived for η Cas, cannot be supported. ϑ Boo and γ Ser have the same luminosity class and spectral type, probably F7 in the system of Geneva.

II. - Considering the degree of metallicity, related to the parameter Δm_2, we observe about equal values in β Com and 47 U Ma and a lesser abundance of metals in η Cas, as it results by the measures shown in Fig. 2, if we suppose that the compared stars have the same classification. Therefore, in this case, the spectroscopic results agree with those photometric and the quantitative analysis confirms the results of Roman.

However if we consider ϑ Boo and γ Ser which also present a rather noticeable difference in the degree of metallicity, remarkable spectroscopic differences are not found (Fig. 2(c)). We note that a lesser abundance of metals results in γ Ser having the space velocity higher than ϑ Boo. It would be interesting to confirm this fact also in other stars. However one can point out that the value of η Cas, (having a low velocity and a degree of metallicity lesser than that of γ Ser) is in disagreement with this remark.

Furthermore we note that the value − 0.030 of ϑ Boo wk-l is similar to the values of the st-l stars of the first group.

According to the measures of several wk-l and st-l stars, HAUCK (1970) has found these *mean* values (probably not definitive):

$$\Delta m_2 = -0.038 \quad \text{for} \quad \text{wk-l} \quad \text{stars}$$
$$\Delta m_2 = -0.019 \quad \text{for} \quad \text{st-l} \quad \text{stars}$$

However, noticeable differences from these values can be found for single stars, as we have seen above.

The abundance of the metals in the observed stars has been computed by means of the relation given by HAUCK (1968):

$$[\mathrm{Fe/H}] = 6.746\ \Delta m_2 + 0.253$$

We find:

β Com	[Fe H] = +0.01
η Cas	= −0.21
47 U Ma	= +0.03
ϑ Boo	= +0.05
γ Ser	= −0.13

If we take into account that the mean error in [Fe/H] is of the order of ± 0.17, the differences in the computed abundances are in the limits of the errors.

4. - Conclusions

According to the above mentioned results, it seems probable that the wk-l and st-l stars of Roman can be distinguished by the different abundance of the metals. We remember also that according to Chalonge (1958; 1959) these stars are placed on opposite sides in respect to the Σ surface. However the differences of the abundances seem to be so small that, not always, they can be remarked certainly with spectrographic methods, at least with our dispersion. Considering Wellmann's results, one can suppose that also with much higer dispersions the distinction between wk-l and st-l stars of Roman may be difficult.

According to our opinion it is impossible to find a criterion, sure in all the cases, to distinguish the stars of the two groups; moreover it is probable that some stars have been erroneously classified by Roman as wk-l or st-l.

Owing to the little differences of abundance and the errors of classification, it seems probable that Roman's wk-l and st-l stars can be distinguished by photometric methods only when mean values are considered; on the contrary this distinction is difficult, if one considers the single stars.

At last, according to Spite (1966) and Conti and Deutsch (1968), it seems that differences caused by an effect of microturbulence can be excluded.

Probably it would be more suitable to leave the old distinction of Roman of wk-l and st-l stars and to consider the metallicity parameter of a photometric system in seven colours.

After the compilation of this work we have received papers regarding also some stars of Roman: Barry (1970), Nissen (1970), Powell (1970); our results are in agreement with those of these papers. In particular Barry considers Roman's criteria in terms of uvby photometry; he points out that the strong line designation is subject to errors due to the extremely small differences in the spectra and the difficulty of assigning accurate temperature types independent of abundances.

We wish to express our thanks to Dr. Hauck for the valuable discussion with one of us and for kind putting his measures and results at our disposal.

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