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SPECTRAL CLASSIFICATION OF EARLY TYPE STARS. CALIBRATION USING A TV-VIDICON MULTICHANNEL SYSTEM

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RESUMEN

Se ha usado un detector multicanal televisivo para estudiar la clasificación espectral de estrellas O y B tempranas. Nuestros datos observacionales se analizaron de acuerdo con los criterios dados por Walborn (1971), y Conti y Alschuler (1971). Se describen algunas de las peculiaridades de los espectros observados.

ABSTRACT

A television multichannel detector is used to study the spectral classification of O and early B stars. Our observational data are analyzed according to the classification criteria given by Walborn (1971) and Conti and Alschuler (1971). Some spectral peculiarities of the observed objects are pointed out.

Key words: SPECTRAL CLASSIFICATION — STARS: STELLAR PROPERTIES.

I. INTRODUCTION

The aim of this work is to analyse the applicability of classical criteria for photographic spectral classification to the spectra obtained by a TV-Vidicon multichannel system. This detector represents a preliminary experiment with television techniques and has been designed to yield good stability in wavelength, linearity and accuracy in response (Firmani *et al.* 1976). At present the sensitivity is only three to five times that of a photographic plate, and will be increased in the future by the use of two input intensifier tubes. The output is in analogical and digital forms, simplifying thus the data handling. In this work we have used the analogical output to compare spectra in terms of equivalent widths.

The spectra have been divided into two groups:

a) O9 to B1.5, where the visual classification criteria given by Walborn (1971) have been verified.

b) O4 to O9, where the spectra have been analyzed using the visual classification criteria given by Walborn (1971) and by means of the criteria proposed by Conti and Alschuler (1971), in which the ratio of equivalent widths,

$$W' = \frac{W\ (4471\ \text{He I})}{W\ (4541\ \text{He II})}$$

is used.

II. OBSERVATIONAL DATA

We have obtained all our spectra between September, 1975 and February, 1976 with the Cassegrain spectrograph of the 40″ telescope, of the National University of Mexico, at Tonantzintla. The vidicon tube coupled to a 500 multichannel device, described by Firmani *et al.* (1976) was used. The resolution of our spectra is 1.6 Å/c; the exposure time for magnitude ten is approximately twenty

TABLE 1

STANDARD STARS O9-B1.5

S. T.	Dwarfs (V)	Giants (III)	Supergiants (I)
O9	10 Lac	ι Ori	τ CMa(Ib)*
O9.5	AE Aur	HD 189957	19 Cep(Ib), α Cam(Ia)
O9.7			ζ Ori(Ib), HD 195592(Ia)
B0	ν Ori		69 Cyg(Ib)*, ε Ori(Ia)
B0.2	τ Sco	HD 195229*	
B0.5	HD 36960		HD 192422(Ib)*, κ Ori(Ia)
B0.7	HD 201795	ε Per	HD 190919(Ib), κ Cas(Ia)
B1	ω^1 Sco	σ Sco	ζ Per(Ib), HD 13854(Iab)
B1.5	HD 154445	12 Lac	HD 193183(Ib)*, HD 190603(Ia)

* The star is not a Walborn (1971) standard.

NOTES TO TABLE 1

α Cam (HD 30614). Weak emission at N III λλ4634-41, with an absorption profile at the center (Figure 1). There are two unidentified emission features at λ4485 and λ4503; Conti (1973) suggests that these lines are associated with C III.
ι Ori (HD 37043). Weak emission profile at N III λλ4634-41, similar to that in α Cam.
ε Ori (HD 37128). Weak emission at N III λλ4634-41.
τ CMa (HD 57061). Weak emission at N III λλ4634-41, similar to that in α Cam is present in one of the spectrograms; it is absent in other two spectrograms taken one month later.
HD 189957. Weak emission profile at N III λλ4634-41, similar to that in α Cam. Also the two unidentified emissions features at λ4485 and λ4503 are present.
HD 195592. Very strong emission at N III λλ4634-41. Two unidentified emissions at λ4485 and λ4503.

minutes. The observed stars are listed in Tables 1, 2 and 4. The ratio of equivalent widths was evaluated from the graphs obtained directly from the analogical output, without using any equipment response, atmospheric or filtering corrections. The spectral continuum was visually interpolated around the spectral lines.

III. O9-B1.5 CLASSIFICATION

To check our observations against Walborn's criteria we obtained most of the spectra of the stars defined as standards by Walborn (1971), as well as those of a few other stars classified by Walborn (1971), Conti and Alschuler (1971), and Johnson and Morgan (1953). Table 1 lists the observed stars and their spectral classification. Some of the spectra are shown in Figures 1 and 2.

All the main criteria of Walborn's two dimensional classification are verified by our spectra. The fact that the ratios (4471 He I)/(4541 He II) and (4541 He II)/(4552 Si III) can be used as temperature indicators in the spectral range O9 to B0 is well confirmed by our results. For example, the intensities of the lines Si III λ4552 and He II λ4541 are about equal at spectral type O9.7I, as required by Walborn's definition. At this point, a remark should be made concerning the behavior of the line He II λ4541 as a function of luminosity. In our spectra this line shows an inverse luminosity effect though the decrease of intensity is not as strong as that in He II λ4686 and He I λ4387. This behavior of He II λ4541 is particularly evident at type B0 where the line is clearly visible in luminosity class V, while it disappears in supergiants (see Figure 1). This effect suggests that the ratio (4541 He II)/(4387 He I) should not be used as a good luminosity indicator, as accepted in the MK system.

In the range between B0 and B1.5 the temperature indicator is given by the ratio (4089 Si IV)/(4552 Si III). This has been also confirmed by our results. The maximum intensity of Si IV λ4089 in

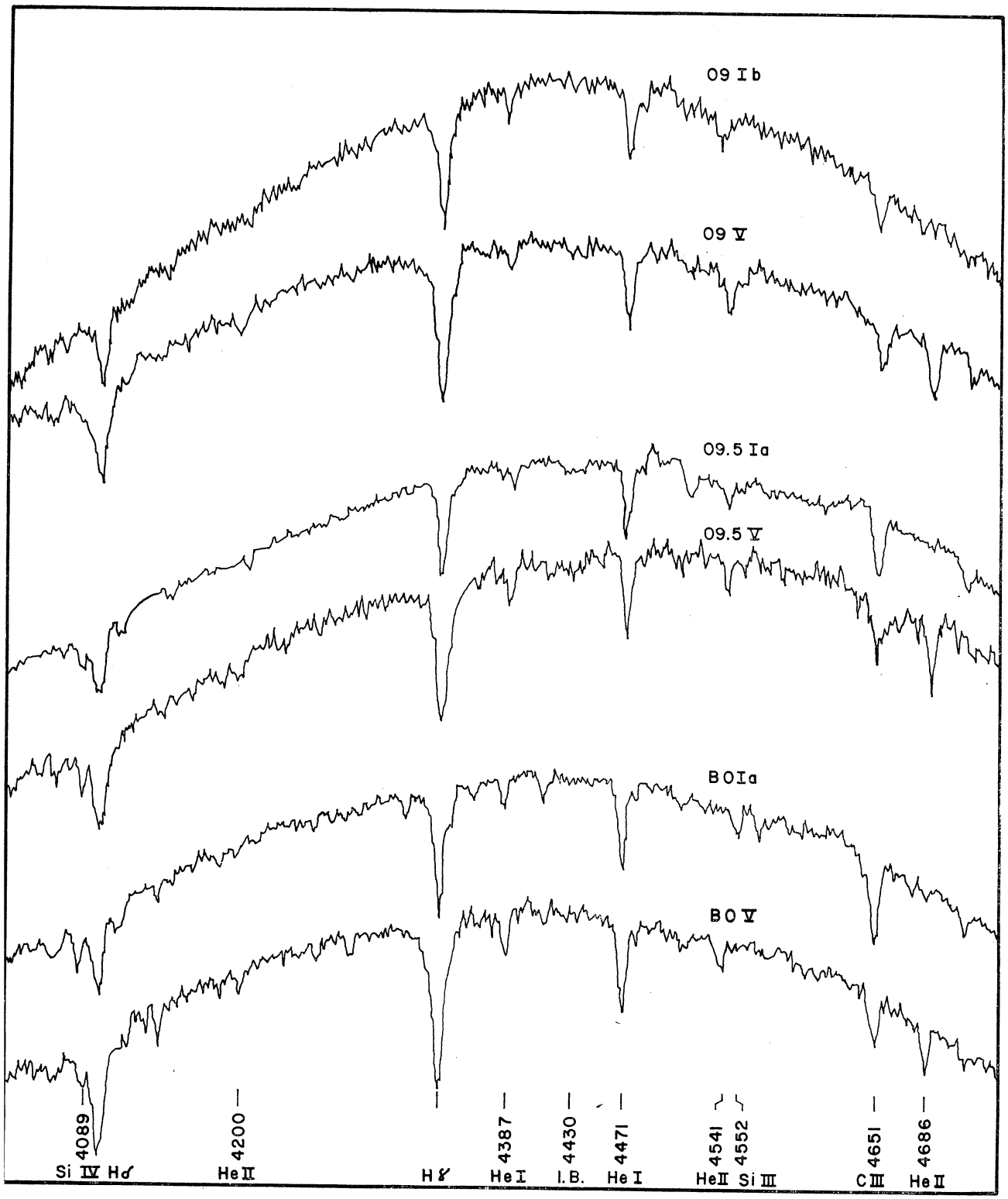

FIG. 1. Tracing of the spectra of the stars (from top to bottom): τ CMa, 10 Lac, α Cam, AE Aur, ε Ori, υ Ori.

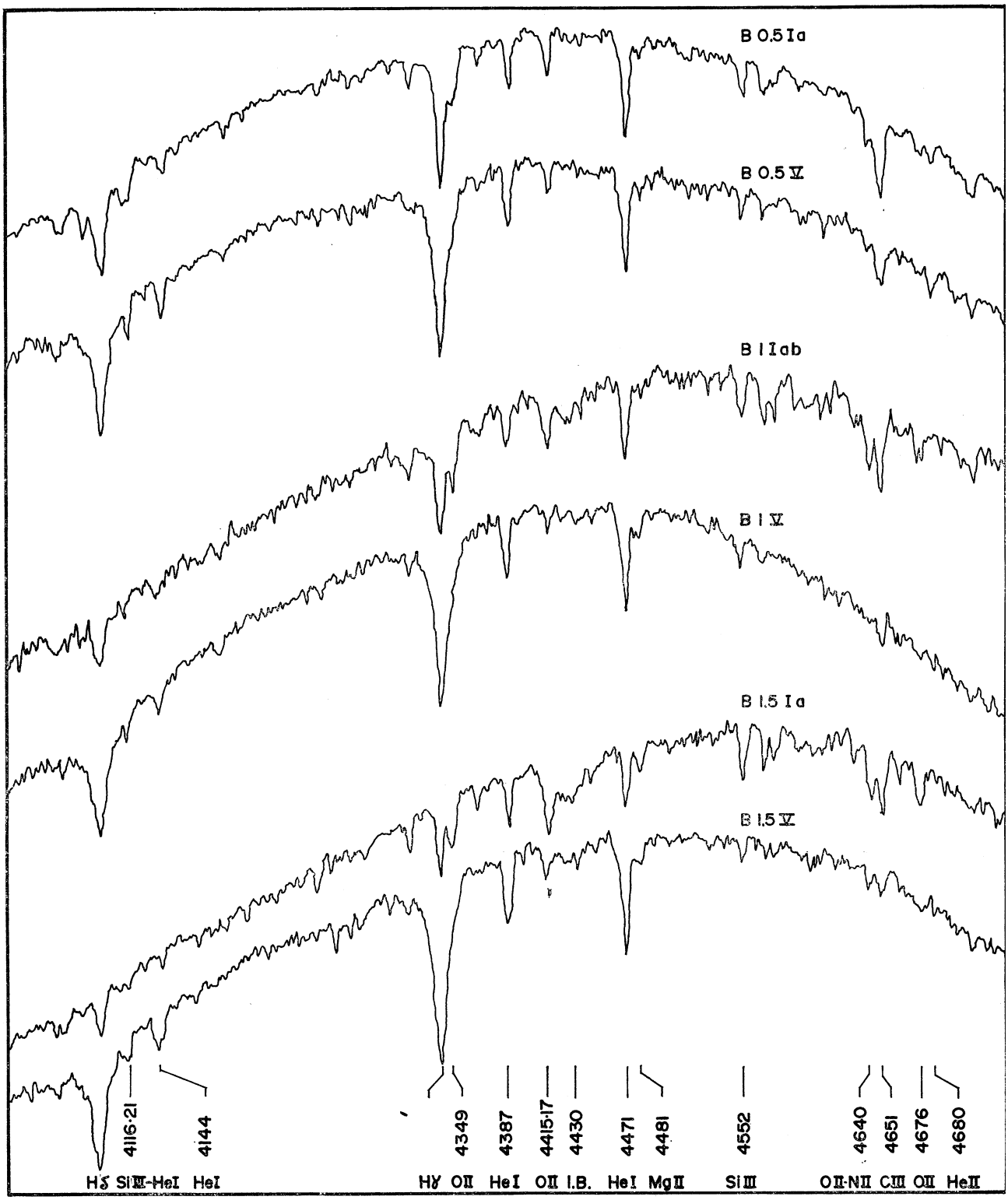

FIG. 2. Tracing of the spectra of the stars (from top to bottom): κ Ori, HD 36960, HD 13854, ω' Sco, HD 190603, HD 154445.

our spectra is found at type B0 for luminosity class I and at type O9.5 for class V. The intensity of this line becomes negligible at B1.5 for supergiants and at B0.5 for the main sequence stars. For the other line Si III λ4552 we find that the maximum intensity falls at B1.5 for supergiants and between B0.5 and B0.7 for class V, the intensity being negligible at B0 and B1.5 for the latter and in O9.5 for the former.

In some cases we had to make use of criteria based on lines of other elements besides He and Si, such as O II, N II, and Mg II. This was necessary because: in the violet, the optical quality and transparency of our camera are poor, the quantum efficiency of the detector decreases, and Si IV λ4089 is sometimes strongly affected by the blue wing of Hδ; hence, the ratio (4089 Si IV)/(4552 Si III) is not easy to evaluate. This might be the reason why we estimate the intensity of Si III λ4552 at B0.7 I to be stronger than that of Si IV λ4089, in contradiction to Walborn's definition which requires the intensities of the two lines to be almost equal.

The intensity of He II λ4686 is a good indicator of luminosity in the range between O9 and B0.5. Upon reaching the later type, the line becomes too faint to be used. Instead, due to the opposed behavior of Si III λ4552 and He I λ4387 as function of luminosity the ratio between the two can be used for luminosity classification in later types. We also considered as a good additional luminosity criterion the intensity of C III-O II λ4650, which shows a strong direct luminosity effect at spectral types B0.5 to B1.5.

IV. O4-O9 CLASSIFICATION

Our results and those by Conti and Alschuler (1971) and by Walborn (1971, 1973), are presented in Table 2. Some of the spectra are shown in Figure 3.

Description of Table 2 by columns:

1) Identification of the star.
2) Number of spectra used in this paper.
3) Average ratio of the equivalent widths W′ = W (4471 He I)/W(4541 He II) from our spectra.
4) The spectral type that corresponds to the ratio W′ using Conti's classification scale. The luminosity class is fixed according to the criteria explained below.
5) and 6) Equivalent width ratio, W′(C) and spectral classification as given by Conti and Alschuler (1971).
7) Walborn's (1972, 1973) visual classification.

In our spectra we find no contradiction between Conti's and Walborn's classification systems as noted by Walborn (1971). Indeed the three stars HD 46223, HD 46150 and 15 Mon (HD 47839) considered by Walborn (1972) as standards for the spectral types O4, O5, and O7, but classified by Conti as O5, O6 and O8, respectively, fall according to our measurements of equivalent width ratios and using Conti's scale, in the types established by Walborn.

In Table 3 we list the equivalent width ratios for three stars obtained from different spectra with our equipment. The dispersion around the mean value suggests a probable error $\lesssim 0.5$ of a spectral class. Taking into account this probable error the agreement of our results with those by Conti and Alschuler, and Walborn (cf. Table 2) seems quite satisfactory. It should be noted, however, that in the average we obtained spectral types earlier than those given by Conti and Alschuler (1971). The difference might be related to a possible peculiarity that is clearly shown in the spectra of HD 46149 and HD 54662, in which there are very wide wings at the line He II λ4541, as illustrated in Figure 4. This effect introduced such an ambiguity in the identification of the stellar continuum, that the results of our measurements of these two stars were omitted in Table 2. To a lesser extent, the same effect could be present in some other spectra, this being a feasible explanation to our tendency to find values for the equivalent widths of He II λ4541 greater than those measured with a much larger dispersion (16 Å/mm) by Conti. It is quite improbable that the above mentioned "wings" could be an instrumental effect at the feature is present in more than one spectrum of the same star, taken at different observing runs. We have found no reference to this problem in the literature.

TABLE 2

SPECTRAL CLASSIFICATION FOR O STARS

NAME	n	W'	S.T.	W'(C)	S.T.(C)	S.T.(W)
HD 108	1	0.40	O5.5fp	0.59	O7If	O6fp
HD 15558	1	0.29	O5III(f)	0.28	O5f	O5III(f)
HD 15570	1	≳ 0	O4If+	0.06	O4f	O4If+
HD 17603	1	1.33	O8If	1.58	O8.5If	O7.5Ib(f)
HD 24431	1	2.88	O9V	2.14	O9V	O9III
HD 24912	6	1.15	O7.5III(f)	1.12	O7.5I	O7.5III((f))
HD 34656	1	0.90	O7III(f)	0.98	O7If	O7II(f)
HD 36486	2	2.72	O9III	3.80	O9.5I	O9.5II
HD 36861	4	1.34	O8III((f))	1.35	O8IIIf	O8III((f))
HD 37022	2	0.73	O6.5III	1.07	O7	
HD 36879	1	0.99	O7V	1.10	O7.5III	O7V
HD 37468	1	3.01	O9:5V	4.90	O9.5V	
HD 38666	1	1.91	O8.5V	2.51	O9V	O9.5V
HD 41161	1	1.26	O8V	1.55	O8V	O8V
HD 42088	1	0.65	O6.5V	0.69	O6.5V	O6.5V
HD 46149	3	*	*	1.86	O8.5V	O8.5V
HD 46150	2	0.29	O5V((f))	0.49	O6f	O5V((f))
HD 46223	1	≳ 0	O4V((f))	0.28	O5f	O4V((f))
HD 46573	1	0.95	O7III((f))	1.14	O7.5Vf	O7III((f))
HD 46966	2	1.17	O7.5V	1.69	O8.5V	O8V
HD 47129	1	1.09	O7.5If	1.35	O7.5IIIf	O8p
HD 47839	7	0.99	O7V	1.32	O8IIIf	O7V((f))
HD 48099	2	0.64	O6.5V((f))	0.69	O6.5V	O7V
HD 52533	1	1.97	O8.5IV	1.74	O8.5V	
HD 53975	1	0.97	O7V	1.23	O7.5V	O7.5V
HD 54662	4	*	*	0.81	O7III	O6.5V
HD 57060	3	1.24	O7.5If	1.66	O8.5If	O7Ia fp
HD 57061	2	2.14	O9I	2.69	O9I	O9II
HD 57682	2	2.08	O9V	2.69	O9V	O9IV
HD192639	1	0.96	O7Ib(f)	1.04	O7.5IIIf	O7Ib(f)
HD193322	1	1.73	O8.5V	1.66	O8.5III	O9V
HD203064	1	1.35	O8III((f))	1.38	O8V	O7.5III((f))
HD210839	1	0.69	O6.5If	0.57	O6f	O6If
HD216898	1	2.60	O9V	2.88	O9V	O9IV

* The lack of data is explained in the text.

NOTES TO TABLE 2

HD 15558. Besides those identified as N III λλ4634-41 and C III λλ4647-50 there is a very wide emission toward the red of He II λ4686 (in absorption) and two other emissions, one toward the violet of He II λ4541 (possibly N III λ4534) and the other toward the violet of He II λ4471, not identified.
HD 24912. The intensities of N III λλ4634-41 in emission, and He II λ4686 in absorption are variable in our spectra.
HD 34656. The disagrement between different luminosity classification of the star may be due to a variation in the intensity of the emission lines. As a matter of fact, Swings and Struve (1940) report the absence of emission lines in the spectra they obtained for this star.
HD 37022. We have not found in our spectra the inverse P Cyg profile in He II λ4686, reported by Conti and Alschuler (1971), but in two exposures taken at different times He II λ4686 shows an appreciable profile variation. Sletteback (1956) reports a faint emission at He II λ4686.
HD 46149. In two of the three spectrograms of this star, all taken at different nights, the profile of He II λ4541 is very similar to that shown in Figure 4. In the third spectrogram the profile appears very different. More observations are needed to be sure of the origin of this variation.
HD 46966. N III λλ4510-34 seems to be variable: it is strong in one exposure and negligible in others.
HD 47129. In our spectra N III λλ4634-41 and He II λ4686 in emission ,are very strong, with variable profiles. Slettebak (1956) reports very weak emission at these lines.
HD 47839. In only one of the seven spectrograms N III λλ4510-34 appears strong, in the others it is negligible. N III λλ4634-41, reported in emission by Slettebak (1956), does not appear in our spectra.
HD 54662. The very broad wings of He II λ4541 shown in Figure 4, are present in all of our spectra.
HD 57060. The strong intensities of the emission lines N III λλ4634-41 and He II λ4686 tend to give support to our classification as compared to that by Conti and Alschuler (1971). The profiles of the He lines are variable; Luyten and Ebbighausen (1935) report the star as being a binary with a four day period.
HD 210839. A weak unidentified emission is present at λ4485, this is quite unusual at the spectral type of this star.

TABLE 3

ACCURACY TEST

HD 47839 (O7V)	HD 24912 (O7.5I)	HD 36861 (O8III)
W′	W′	W′
0.87	1.07	1.38
1.00	1.15	1.33
1.00	1.12	1.30
0.94	1.13	1.30
1.07	1.16	
1.00	1.24	

TABLE 4

SPECTRAL CLASSIFICATION FOR SOME O STARS

NAME	n	W′	S.T.	S.T.(CGO)
HD 37737	1	3.35	O9.5II	O9.5III
HD 41997	1	1.24	O7.5III	O7.5V
HD 44811	1	0.94	O7V	O7V
HD 55879	1	5.09	O9.7Ib	O9.5II–III
HD 66811	3	0.19	O4If	O4If
HD 68450	1	5.42	O9.7II	O9.7Ib
HD 93521	3	2.72	O9II	O9Vp
HD 225160	1	1.30	O8I(f)p	O8Ib(f)

NOTE TO TABLE 4

HD 225160. Two unidentified emission features are present at λ4485 and λ4503. N III λλ4510-34 is unusually strong the star may be over abundant in N (see Figure 5).

For the luminosity classification we used Walborn's (1971) and Conti and Alschuler's (1971) criteria, which are essentially identical. The intensities of N III λλ4634-41 and He II λ4686, in emission and absorption, were considered as luminosity indicators.

We searched for a relation between the intensity of N III λλ4510-34 and the luminosity or temperature of the stars. Although the blend seems to be present with a higher frequency in the spectral range between O7 and O9, no correlation between the intensity of it and the luminosity or temperature of the star could be found. Furthermore, in some cases (cf. notes to Table 2), the intensity of this feature seems to vary in some of the observed stars. Finally, Table 4 shows the data for some stars for which no equivalent width ratios were obtanied by Conti. Our results appear in the same order as in Table 2, together with the classification adopted in the CGO catalogue, by Cruz-González *et al.* (1974).

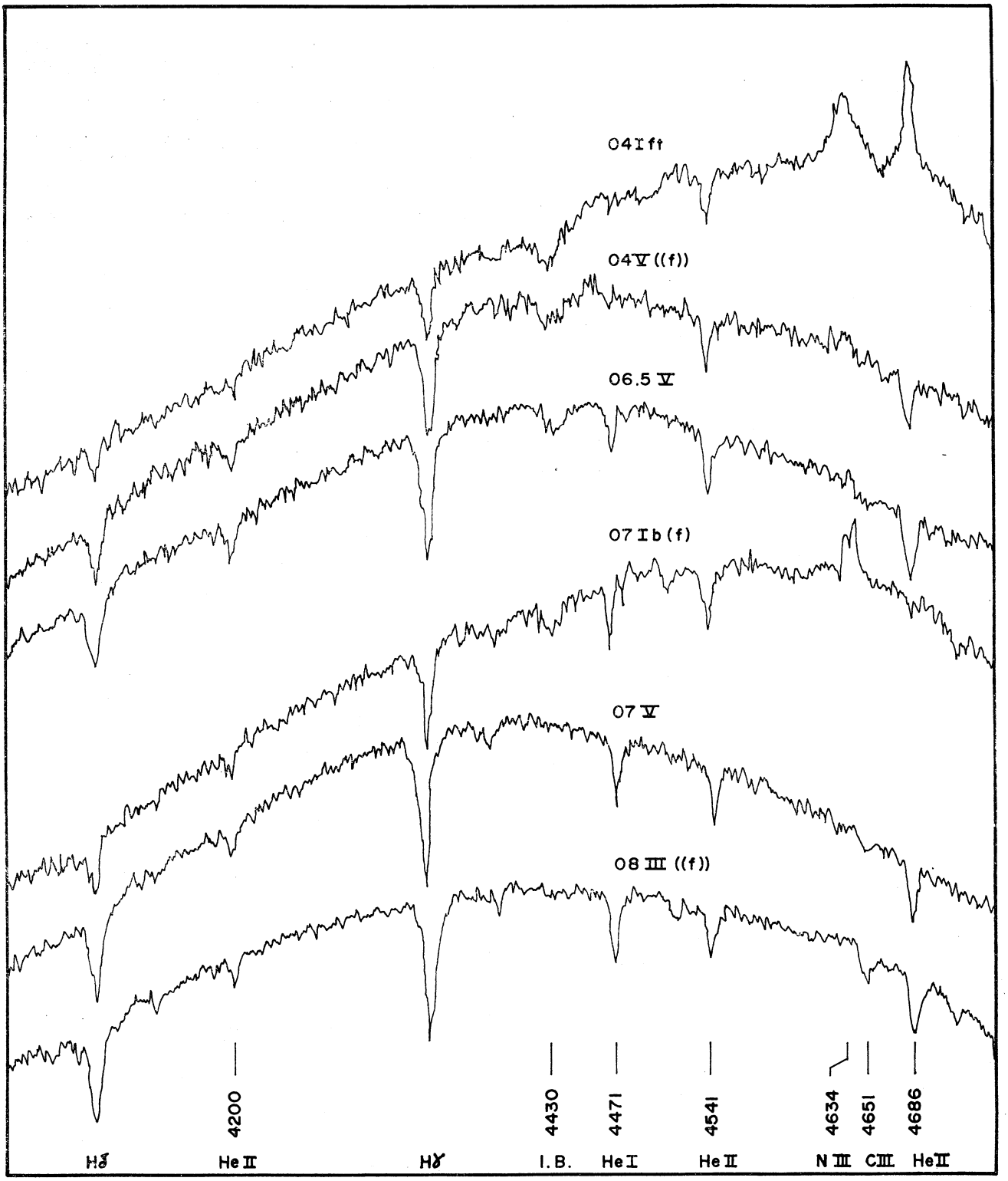

FIG. 3. Tracing of the spectra of the star (from top to bottom): HD 15570, HD 46223, HD 42088, HD 192639, HD 47839, HD 36861. The spectral type shown in the Figure corresponds to our classification.

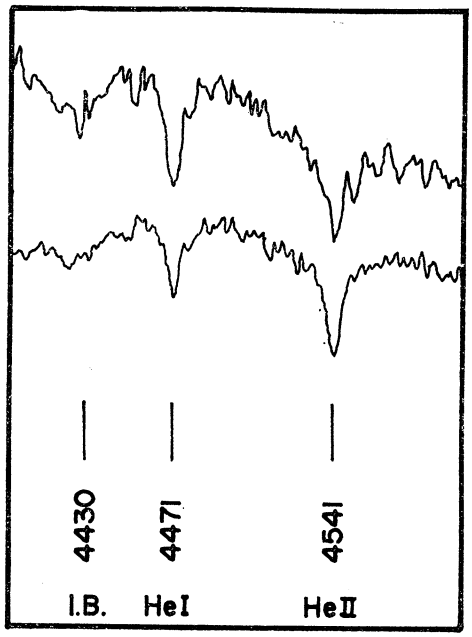

FIG. 4. Tracing of the spectra presented correspond from top to bottom to the stars HD 46149 and HD 54662. The difficulty in tracing the spectral continua around He II λ4541 is evident.

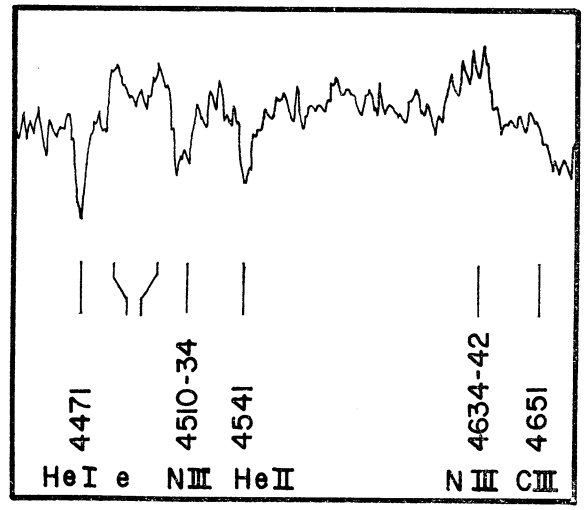

FIG. 5. Tracing of the spectrum of HD 225160 between He I λ4471 and C III λ4651. The unusual intensity of N III λλ4510-34 is clear.

V. CONCLUSIONS

By our TV-Vidicon multichannel system we obtain spectra from which, without any preliminary corrections, two dimensional spectral classification of early-type stars can be obtained. We estimate the error in spectral type, for stars between O4 and B2, to be equal to, our smaller than 0.5. We believe that spectral classification with and analogous quality can be achieved on stars as late as F.

Our spectral classification of O-type stars tends to bring into agreement the classification systems by Conti and by Walborn. It is possible that the differences, noted by Walborn (1972) are due to the larger dispersion used by Conti and Alschuler (1971) with respect to the dispersion used by Walborn (1972-73) and by us.

In some stars we noted a variation of emission lines intensities on a time scale of a few weeks. Further observations of these objects should be interesting.

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