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# Spectrographic Observations of ζ Aurigae during the 1963-64 Eclipse

By

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With 5 Figures in the Text

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The eclipsing system ζ Aurigae has been observed with the grating spectrograph of the Merate Observatory (dispersion 22 A/mm) from September 1963 to February 1964. Intensity variations and radial velocities of the chromospheric lines have been measured. The chromospheric K line has been observed first appearing 57 days before mid-totality and disappearing 43 days after mid-totality. By comparison of the K-type spectrum, observed during totality and the B + K spectrum observed completely out of totality, the B-type spectrum has been derived. The spectral type is B 7 $\leqq$ Sp $\leqq$ B 9 and the luminosity class IV or V. The quantum number of the last visible Balmer line is $n = 18$, and for the Balmer discontinuity were found the following limits: $0.34 \leqq D \leqq 0.52$.

## 1. Introduction

According to the plan of international cooperation for the observation of ζ Aurigae, we have observed this system with the grating spectrograph of the Merate Observatory. The dispersion used is 22 A/mm in the third order and the spectral range ist λλ 3500—4500 A. Only a few spectrograms during the totality were taken with a dispersion of 35 A/mm in the second order, since the atmospherical conditions made it difficult to increase adequately the exposure time. Because of bad weather conditions we have no plates just before and after totality.

The epoch of the eclipse has been computed using the following data: J.D. 2432553.666 + 972.162 E (Wood, 1951). Hence for the epoch of mid-eclipse we have J.D. 2438386.638. This value is not contradicted by the photometric observations by Kondo and Harris (1964).

## 2. Variation of the intensity of the chromospheric lines

Fig. 1 gives the intensity variations of the chromospheric K lines observed during this eclipse together with the results of previous eclipses.

During the 1963—64 eclipse the intensity variation is in between those indicated as "normal" and "abnormal" according to McKELLAR and PETRIE (1957). As we can see from Fig. 1 the chromospheric K line was abnormally strong only during the ingress phase of the eclipse of 1937 which was observed by BEER (1940). This effect is probably real and not instrumental since the same observer, using the same equipment, found good agreement with the Victoria observations during the egress phase of the 1934 eclipse when the K line showed a normal behavior. The first appearance of the chromospheric K line occurred 57 days before mid-totality and the last appearance about 43 days after the same date. The usual asymmetry in the intensity decrease of the K line is found. At the egress, and precisely at the dates J.D. 2438419.311, 2438420.243 and 2438421.236, we observed the probable presence of a central emission component of the chromospheric K line which gradually decreased in intensity from the first to the third day.

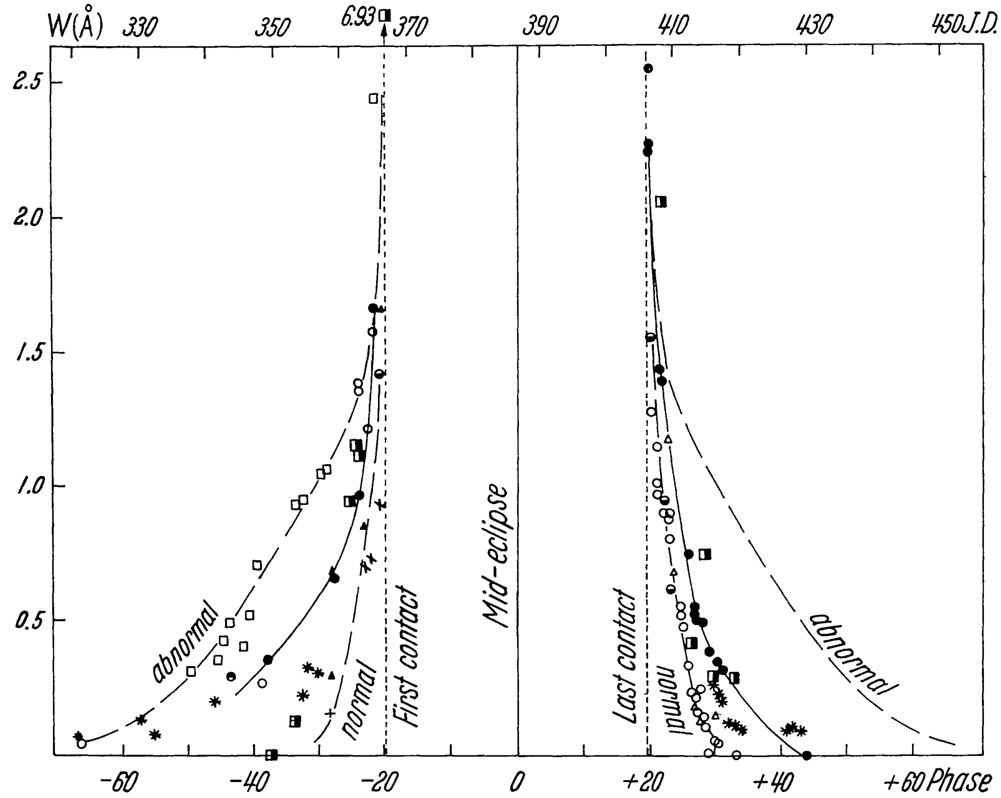

Fig. 1. Intensity variations of the K chromospheric line of Ca II. ◒ 1934 CHRISTIE and WILSON (19 A/mm at 3800 A); △ 1934 BEER (31 A/mm at K-line); □ 1937 BEER (31 A/mm at K-line); ◓ 1937 Victoria (20 A/mm); × 1939—40 WILSON (10.4 A/mm); + 1939—40 Victoria (20 A/mm); ○ 1947—48 WELSH (19.9 A/mm at K-line, 26.4 A/mm); ● 1950 Victoria (20 A/mm, 33 A/mm); ▲ 1953 Victoria (34 A/mm at K-line); ◨ 1955—56 Victoria (3.6 A/mm, 16 A/mm, 34 A/mm, 60 A/mm); ✱ 1963—64 FARAGGIANA (22 A/mm)

Table 1. *The observations*

| Date | J.D. | Spectrogram | Phase | Notes |
|---|---|---|---|---|
| Sept 28, 1963 | 2438,300.578 | Fa 1828 | —86.060 | weak |
| Sept 29 | 301.562 | Fa 1833 | —85.076 | weak |
| Oct 5 | 307.562 | Fa 1838 | —79.076 | good |
| Oct 6 | 308.511 | H 1841 | —78.127 | very weak |
| Oct 7 | 310.464 | H 1843 | —76.174 | good |
| Oct 8 | 310.503 | H 1844 | —76.135 | good |
| Oct 9 | 311.590 | Fa 1853 | —75.048 | good |
| Oct 10 | 312.566 | H 1861 | —74.072 | good |
| Oct 10 | 313.449 | Fa 1863 | —73.189 | weak and slightly doubled |
| Oct 11 | 313.569 | Fa 1864 | —73.069 | good |
| Oct 18 | 320.493 | H 1865 | —66.145 | good |
| Oct 22 | 324.535 | H 1866 | —62.103 | good |
| Oct 24 | 326.556 | H 1868 | —60.082 | good |
| Oct 27 | 329.472 | Fa 1870 | —57.166 | good. First appearance of the chromospheric K line |
| Oct 30 | 332.569 | Fa 1886 | —54.069 | good |
| Nov 7 | 341.393 | H 1894 | —45.245 | good |
| Nov 21 | 354.524 | H 1899 | —32.314 | good |
| Nov 22 | 355.507 | H 1900 | —31.131 | good |
| Nov 23 | 356.483 | Fa 1901 | —30.155 | good, very strong chromospheric K line |
| Dec 7 | 371.344 | Fa 1906 | —15.294 | very weak, totality |
| Dec 12 | 376.243 | H 1912 | —10.395 | weak |
| Dec 21 | 385.329 | AyIJ 1913 | —1.309 | weak |
| Dec 26 | 390.333 | Fa 1914 | +3.695 | second order |
| Dec 27 | 391.299 | Fa 1916 | +4.661 | fairly good |
| Dec 28 | 392.337 | Fa 1921 | +5.699 | second order |
| Jan 2, 1964 | 397.314 | J 1930 | +10.676 | good |
| Jan 4 | 399.317 | Fa 1931 | +12.679 | good |
| Jan 9 | 404.257 | H 1937 | +17.619 | second order, totality |
| Jan 14 | 409.201 | H 1938 | +22.563 | second order, strong chromospheric K line |
| Jan 21 | 416.307 | HJ 1939 | +29.669 | good |
| Jan 22 | 417.306 | FaH 1941 | +30.668 | good |
| Jan 23 | 418.323 | H 1946 | +31.685 | good |
| Jan 24 | 419.311 | AyIJ 1948 | +32.673 | good, K line emission component? |
| Jan 25 | 420.243 | AyFaI 1949 | +33.605 | good, K line emission component? |
| Jan 26 | 421.236 | Fa 1959 | +34.598 | good, K line emission component? |
| Jan 31 | 426.262 | AyIJ 1966 | +39.624 | good |
| Feb 1 | 427.253 | AyFaI 1977 | +40.615 | weak |
| Feb 3 | 429.302 | H 1980 | +42.664 | good, very weak chromospheric K line |
| Feb 4 | 430.253 | AyHI 1984 | +43.615 | weak |
| Feb 21 | 447.262 | AyIJ 1986 | +60.624 | good, no chromospheric K line visible |
| Feb 23 | 449.255 | AyIJ 1997 | +62.617 | good |

Observers: Ay = C. Aydin, Fa = R. Faraggiana, H = M. Hack, I = S. Islik, J = F. Job.

The variations of the central depths of a number of metallic lines are given in Fig. 2. A slight increase of intensity is visible and especially

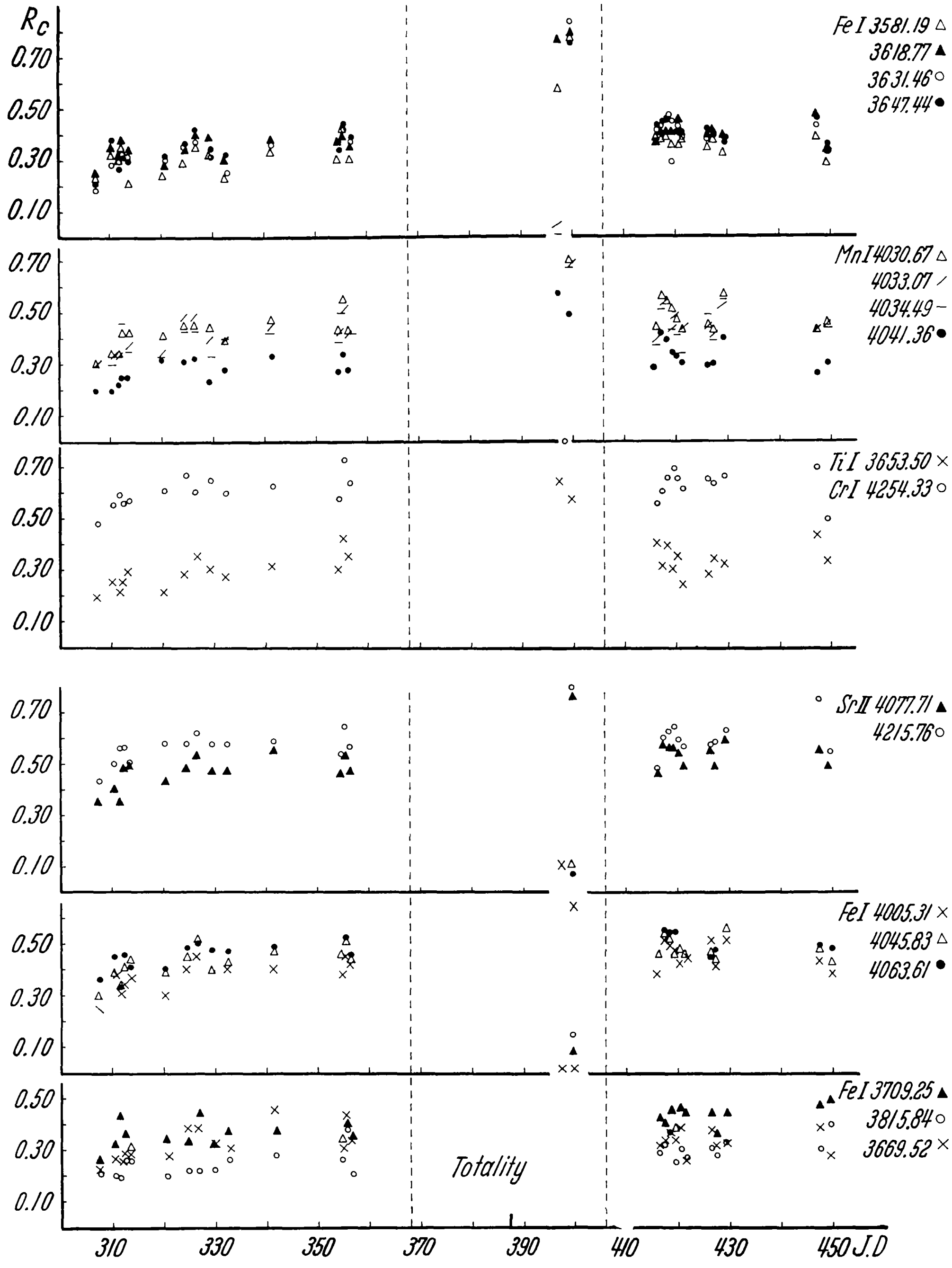

Fig. 2. Variations of the central depths for the metallic lines

apparent in the resonance lines eleven days before the beginning of the partial phase. It is impossible to say whether the same asymmetry observed for the K line is present also for the metallic lines since we have too few observations close enough to the beginning or to the end of the partial phases.

We note a general decrease of intensity at phase —67 and another at phase —54. A similar decrease of intensity at $37.40^d$ before the beginning of totality was found by FRACASTORO (1949). In our case this phenomenon can be better explained by intrinsic variations of the K-type spectrum rather than by assuming that the outer envelope of the K-type star is not homogeneous. In fact, at phase —54 the effect of the chromosphere is barely visible only in the K line. We note that the increase of intensity observed during totality is much more evident in the short wave lengths where the contribution of the companion is more important. The ratio between $R_c$ measured during totality to $R_c$ measured out of eclipse ranges from about 3 at $\lambda$ 3600 to about 1.5 at $\lambda$ 4250. On a few spectrograms taken by MAMMANO (1965) at the Asiago Observatory, an extremely sharp increase in the Ti II lines at $\lambda\lambda$ 3759.29, 3761.32 and 3685.19 is observed at phases —27, —26 and —25 from mid-eclipse. At the phases —32 to —30 on our spectrograms these same lines are not stronger than the other chromospheric lines, and show a behavior very similar to that of the resonance line $\lambda$ 3653.50 Ti I.

### 3. Radial velocities

We have measured the radial velocities of several lines in the range $\lambda\lambda$ 3500—4070; all these lines, with the exception of the chromospheric K line, give a radial velocity which is an average of the stellar velocity and the velocity of the chromospheric gases, since all these lines are blends of the chromospheric and stellar lines. The K line clearly shows the usual behavior as observed during previous eclipses: the radial velocities are usually more positive than the orbital velocity at the beginning of the atmospheric eclipse. However, at two phases (J.D. 2438341.393 and 2438355.507) they are below the orbital velocity curve. At the egress the K line always shows radial velocities below the orbital velocity curve. Fig. 3 shows the radial velocity observations for the K line, and for comparison the analogous observations for previous eclipses. The orbital velocity curve is that computed by MCKELLAR and PETRIE (1952) which has an intermediate value between those by HARPER (1924), and by CHRISTIE and WILSON (1935). The behavior observed during this last eclipse is very similar to that observed in 1950, and not to those of 1934, 1939 and 1947—48 when the radial velocities at egress were on the average much lower. In 1955—56, on the contrary, the radial velocity at egress was almost equal to the orbital one. Fig. 4 gives the radial velocities of the other metallic lines. The radial velocities of the characteristic chromospheric line $\lambda$ 3761 Ti II has been compared with those relative to the eclipse of 1955—56 λ 3759 and λ 3761 (McKELLAR and BUTKOV, 1957). The general behavior is confirmed, as well as the individual differences from one eclipse to the other, and also the differences during the same eclipse from one element to another, suggesting different motions of individual clouds at the different levels of formation of the single lines. We note that the two lines which are purely chromospheric,

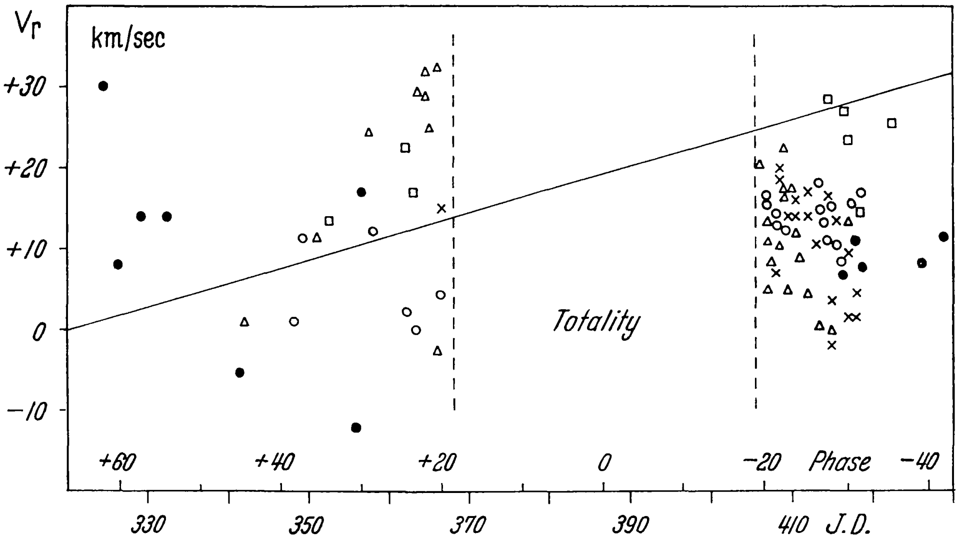

Fig. 3. Radial velocities of the K-line. △ 1934 to 1939 Berlin-Babelsberg, Cambridge and Mt. Wilson; × 1947—48 Victoria; ○ 1950 Victoria; □ 1955—56 Victoria; ● 1963—64 FARAGGIANA

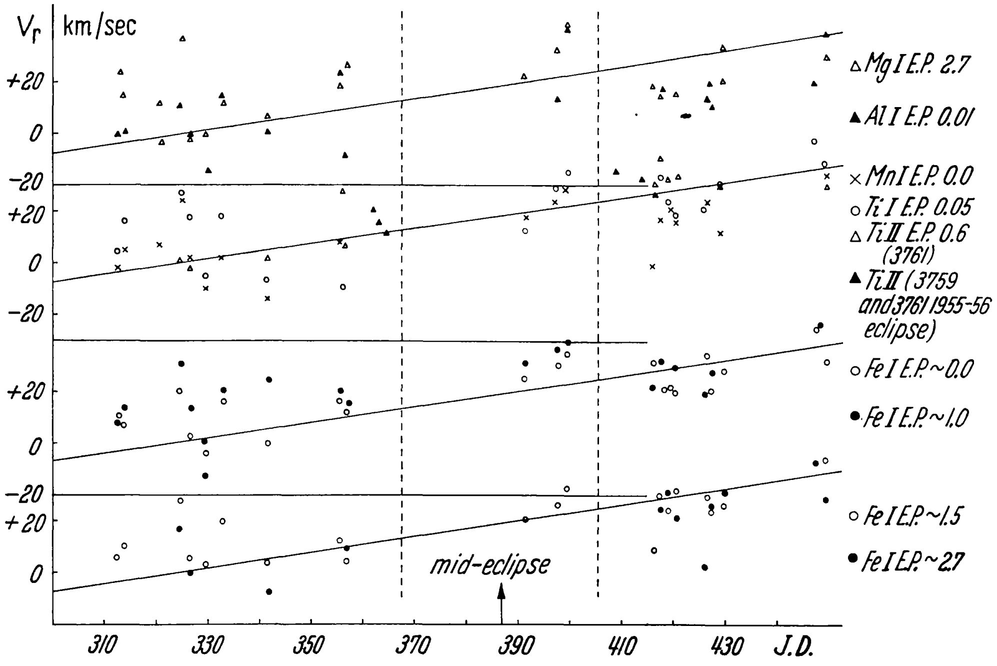

Fig. 4. Radial velocities of the metallic lines

i.e. the chromospheric component of the K line and $\lambda$ 3761 Ti II, do not show the same behavior; the deviations from the orbital velocity curve are smaller for the Ti II line, except at phase $-30$ when it is about 20 km/sec above the orbital velocity curve. At the same epoch the K line shows a velocity of 20 km/sec below the orbital curve. At the egress the Ti II line has a velocity slightly higher than the orbital velocity, i.e. still an opposite behavior from the K line. At the phases when a probable emission is observed in the chromospheric K line, the distance between the two absorption peaks corresponds to 40 km/sec. No satellite lines of the K line have been observed, probably due to the moderate dispersion used, and also because this phenomenon, according to previous observations, is much less evident in $\zeta$ Aurigae than in 31 Cygni (McKellar and Petrie, 1952).

## 4. Determination of the ratio $\alpha$ between the continuous spectra of the B-type star and the K-type star

The method described by Wright and Lee (1959) for the determination of $\alpha$ was used in this case. We employed the same lines which were selected in our previous studies of 31 Cygni and 32 Cygni (1963, 1965), and which fall in regions of the B-type spectrum free from lines (Table 2). The two spectrograms Fa 1853 and Fa 1931, which are the best, the first out of eclipse and the second during totality, were used for the computation of $\alpha$. The continuum has been traced using the same criterion as described for 31 Cygni. The values of $\alpha$ vs. $\lambda$ are more scattered around an average curve than was the case in our previous studies of 31 Cygni and 32 Cygni, using the same equipment and the same method of reduction. Hence, given the difficulty of deciding the best average curve among the observed points, $\alpha$ has been found by successive approximations, adopting various trial values with the purpose of finding a value which would eliminate the presence of the lines of the K-type spectrum from the B-type spectrum derived by the same procedure, i.e. by subtracting the K-type spectrum reduced by the factor $K = \frac{1}{1+\alpha}$ from the B + K spectrum. However, the B-type spectrum derived from this value still presents a residual of the K-type spectrum at $\lambda\lambda$ 3900—3935, $\lambda$ 4005, $\lambda\lambda$ 4030—4060 suggesting that a still higher value of $\alpha$ could be adopted. This, however, will be incompatible with the single observed values of $\alpha$. Moreover, the values we adopted for $\alpha$ are much higher than those adopted by Lee and Wright (1960) with 3.2 A/mm dispersion. For example, Lee and Wright find $\alpha = 3.5$ in the spectral region $\lambda\lambda$ 3812—3855, while we assume $\alpha = 6.2$ for the spectral range $\lambda\lambda$ 3850—4000. Our values are in good agreement with those found by Christie and Wilson (1935) who used a dispersion comparable

Table 2. *Values of* $\alpha$

| Identification | $W_K$ | $W_{BK}$ | $\alpha$ |
|---|---|---|---|
| 3558.52 FeI (24) | 1.29 | .242 | 4.35 |
| 3581.19 FeI (23) | 1.30 | .28 | 3.65 |
| 3593.49 CrI (4) | 1.32 | .186 | 6.1 |
| 3605.33 CrI (4) | 1.28 | .242 | 4.3 |
| 3610.46 NiI (18) | 1.04 | .204 | 4.1 |
| 3618.77 FeI (23) | 1.3 | .307 | 3.25 |
| 3631.46 FeI (23) | 1.42 | .279 | 4.1 |
| 3647.84 FeI (23) | 1.2 | .251 | 3.8 |
| 3649.51 FeI (291) | 0.85 | .251 | 2.4 |
| 3669.52 FeI (291) | 0.777 | .242 | 2.18 |
| 3679.82 CrI (48)<br>3679.91 FeI (5) | 1.16 | .279 | 3.16 |
| 3759.29 TiII (13) | 1.16 | .223 | 4.2 |
| 3815.84 FeI (45) | 1.22 | .177 | 5.9 |
| 3859.91 FeI (4) | 1.45 | .242 | 5.00 |
| 3865.53 FeI (20) | 1.135 | .158 | 6.2 |
| 3899.71 FeI (4) | 1.271 | .242 | 5.25 |
| 4005.25 FeI (43) | 0.883 | .302 | 1.94 |
| 4018.10 MnI (5) | 0.42 | .25 | 0.68 |
| 4030.75 MnI (2) | 1.04 | .363 | 1.87 |
| 4033.07 MnI (2) | 1.01 | .334 | 2.03 |
| 4034.49 MnI (2) | 0.981 | .335 | 1.92 |
| 4041.36 MnI (5) | 0.446 | .202 | 1.20 |
| 4045.81 FeI (43) | 1.46 | .362 | 3.03 |
| 4058.93 MnI (5) | 0.745 | .302 | 1.46 |
| 4063.60 FeI (43) | 1.3 | .344 | 2.48 |
| 4152.77 CrI (261) | 0.82 | .585 | 0.40 |
| 4161.05 CrII (162) | 0.66 | .326 | 1.02 |
| 4177.60 FeI (18) | 0.91 | .372 | 1.45 |
| 4191.44 FeI (152) | 0.93 | .432 | 1.15 |
| 4202.03 FeI (42) | 1.35 | .515 | 1.20 |
| 4210.35 FeI (152) | 0.71 | .511 | 0.40 |
| 4215.52 SrII (1) | 1.375 | .805 | 0.71 |
| 4235.94 FeI (152) | 0.905 | .54 | 0.68 |
| 4239.72 MnI (23) | 0.615 | .372 | 0.64 |
| 4246.83 ScII (7) | 0.53 | .395 | 0.34 |
| 4250.12 FeI (152)<br>4250.72 FeI (42) | 1.04 | .735 | 0.42 |
| 4254.35 CrI (1) | 1.37 | .905 | 0.51 |
| 4258.32 FeI (3) | 0.76 | .576 | 0.33 |
| 4260.48 FeI (152) | 1.04 | .785 | 0.32 |
| 4271.76 FeI (42) | 1.375 | .782 | 0.76 |
| 4274.80 CrI (1) | 1.44 | .75 | 0.92 |
| 4315.09 FeI (71) | 1.05 | .875 | 0.20 |

to ours, i.e. 19 A/mm. Fig. 5 gives our observations for $\alpha$, the adopted average curve, and those by Lee and Wright and by Christie and Wilson for comparison. The jump due to the Balmer discontinuity in the spectrum of the B-type star is clearly visible. By extrapolation of the curve for $\alpha$ we find $\alpha_{3700+\varepsilon} \sim 7.90$. From the two possible values for $\lambda = 3700 - \varepsilon$, $\alpha_{3700-\varepsilon} = 3.60$ and $\alpha_{3700-\varepsilon} = 2.40$, it follows that $0.34 \leqq D \leqq 0.52$.

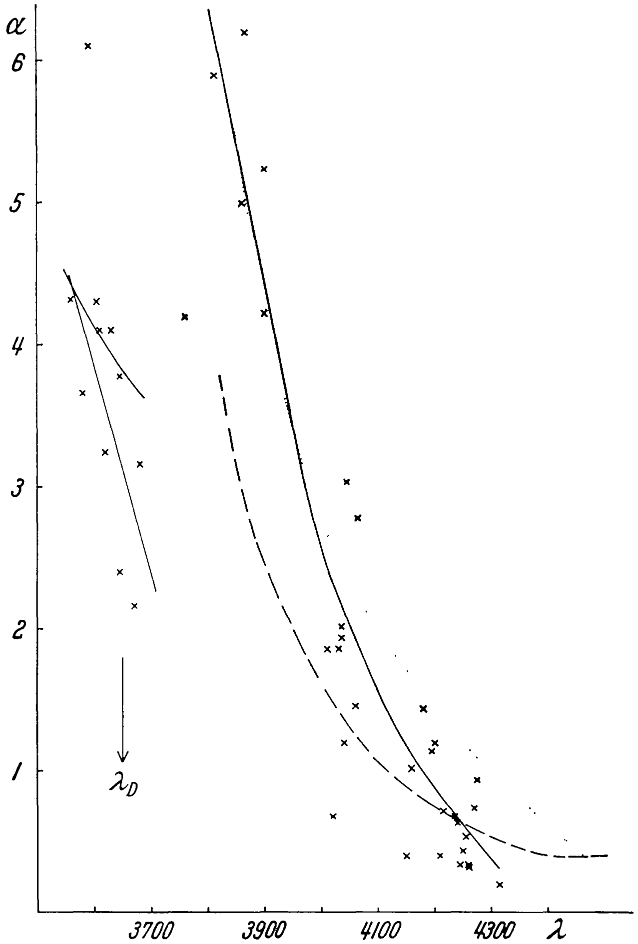

Fig. 5. $\alpha$ versus $\lambda$. · · · · 1934 Christie and Wilson; - - - - 1955 Lee and Wright; ——— 1963—64 Faraggiana

## 5. The spectrum of the B-type star

From the B-type spectrum obtained as described above, we find the following data:

Moreover, the last visible Balmer line is $n = 18$. According to the observations of Wellmann (1951) made with dispersions between 65 and 22 A/mm, $n = 17$, Christie and Wilson (1935) give $n = 19$ and Popper (1961) $n = 17$. These data together with the limits found above for $D$, give the following classifications:

From these criteria we assume that the spectral type for the companion is probably B7 or B8 and the luminosity class IV or V. From the Petrie (1952) relation between the total intensity of $H_\gamma$ and $M_v$, assuming that $W(H_\gamma) \simeq W(H_\delta)$ we find $M_v = -1.1$ which corresponds to type B6 V or B9 IV or A0 III, (KEENAN and MORGAN, 1951). The ratio $H_{8+9}/(3819 + 4026)$ suggests spectral type B7.5. The colors derived from photoelectric measurements during he ectlipse of 1955—56 suggest that the companion has a type between B7 V and B8 V. Hence, summing up all these different indications, the spectral type of the companion is B7 $\leqq$ Sp $\leqq$ B9 and the luminosity class IV or V.

Table 3. *Equivalent widths for B-type spectrum*

| Line | Equivalent widths |
|---|---|
| $H_\delta$ | 6.8 A |
| $H_8$ | 6.7 |
| $H_9$ | 6.5 |
| 3819 HeI | 0.5 |
| 4026 HeI | 0.3 |

Table 4. *Classification of the B-type spectrum*

| Criterion | Spectral Type |
|---|---|
| $0.34 \leqq D \leqq 0.52$ | B7—A0III or IV—V |
| $n = 18$ | B8V |
| $H_\delta$, $H_8$, $H_9$ | B7IV—V or A0III |
| 4026, 3819 HeI | B7 |

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