Zeitschrift für Astrophysik 64, 48—53 (1966)

Pubblicazioni dell'Osservatorio Astronomico di Trieste Nr. 342

A Comparative Study of the Three K-type Members of the Systems ζ Aurigae, 31 Cygni and 32 Cygni

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Received December 1, 1965

The spectra of the K-type components of ζ Aur, 31 Cyg and 32 Cyg, observed during totality, are compared. 32 Cyg has higher microturbulence velocity and lower damping than the other two stars. The slope of the relation $m_K - m_B$ versus $1/\lambda$ for ζ Aur is appreciably higher than for 31 and 32 Cyg. Assuming $T_B \geqq 10000°$ K, the color temperature T_K ranges between 2000 and 2500° for ζ Aur and 2500 and 3000° for 31 and 32 Cyg. These low values are due to the fact that the continuum is depressed by overlapping absorption lines. The apparently lower temperature of ζ Aur is attributed to the larger width of the absorption lines which cause a larger masking of the continuum. This broadening is probably due to rotation which is faster than in the other two stars. This higher rotational velocity could also explain the different behavior of the radial velocities of the chromospheric lines just before and after totality; they are red-shifted before and violet-shifted after totality in ζ Aur, while in 31 and 32 Cyg they are violet-shifted both before and after totality.

Es werden die während der Totalität aufgenommenen Spektren der K-Komponenten von ζ Aur, 31 Cyg und 32 Cyg verglichen.

32 Cyg zeigt höhere Mikroturbulenzgeschwindigkeit und niedrigere Dämpfung als die beiden anderen.

Die Neigung der Kurve, welche $m_K - m_B$ als Funktion von $1/\lambda$ darstellt, ist für ζ Aur viel größer als für 31 und 32 Cyg. Dies wird der Tatsache zugeschrieben, daß das kontinuierliche Spektrum von ζ Aur durch Überlagerung der Absorptionslinien stärker herabgedrückt wird als bei den beiden anderen Sternen. Tatsächlich sind alle Spektrallinien von ζ Aur breiter als die entsprechenden Linien von 31 und 32 Cyg. Diese größere Breite wird einer höheren Rotationsgeschwindigkeit zugeschrieben. Hierfür spricht auch das Verhalten der Radialgeschwindigkeit der chromosphärischen Linien vor und nach der Totalität: bei ζ Aur sind sie vor der Totalität nach Rot und nach der Totalität nach Violett verschoben, während sie bei 31 und 32 Cyg vor und nach der Totalität eine Violettverschiebung zeigen.

1. Introduction

We have made a comparison of the spectra of the K-type components of the three systems ζ Aur, 31 Cyg and 32 Cyg. The spectral types of the K and B components respectively, given in the literature (McKellar and Petrie, 1958) are K3 or K4 Ib and B8 V; K3 or K4 Ib and B5 V; K5 I and B3 V. However the slope of the relation $\log \alpha$ versus $1/\lambda$ (with $\alpha = I_{cB}/I_{cK}$) for ζ Aur is appreciably higher than for 31 and 32 Cyg. Since the B component is certainly of later spectral type than in 31 and 32 Cyg (as the broad Balmer lines indicate), this behavior at first might suggest that the K component of ζ Aur is of spectral type later than that of 31 and 32 Cyg, contrary to the spectral types estimated in the literature.

Since we have observed all the three systems during the last eclipses (Faraggiana and Hack, 1963; Faraggiana et al., 1965; Faraggiana, 1965) and have spectrograms of the K-components taken during totality with the same equipment (grating spectrograph at the 1 m reflector of the Merate Observatory), we have thought it worthwhile to make a comparative study of these three spectra.

The spectrograms have been taken in the third order with emulsion Eastman Kodak 103 Ao. The dispersion is 22 A/mm and the spectral range λλ 3500—4500.

Table 1. *The observations*

Star	Spectrogram	Date	Slit image on plate
31 Cyg	H 962	1962 Feb. 13	22 μ
32 Cyg	H 1128	1962 June 4	22
ζ Aur	Fa 1931	1964 Jan. 4	22

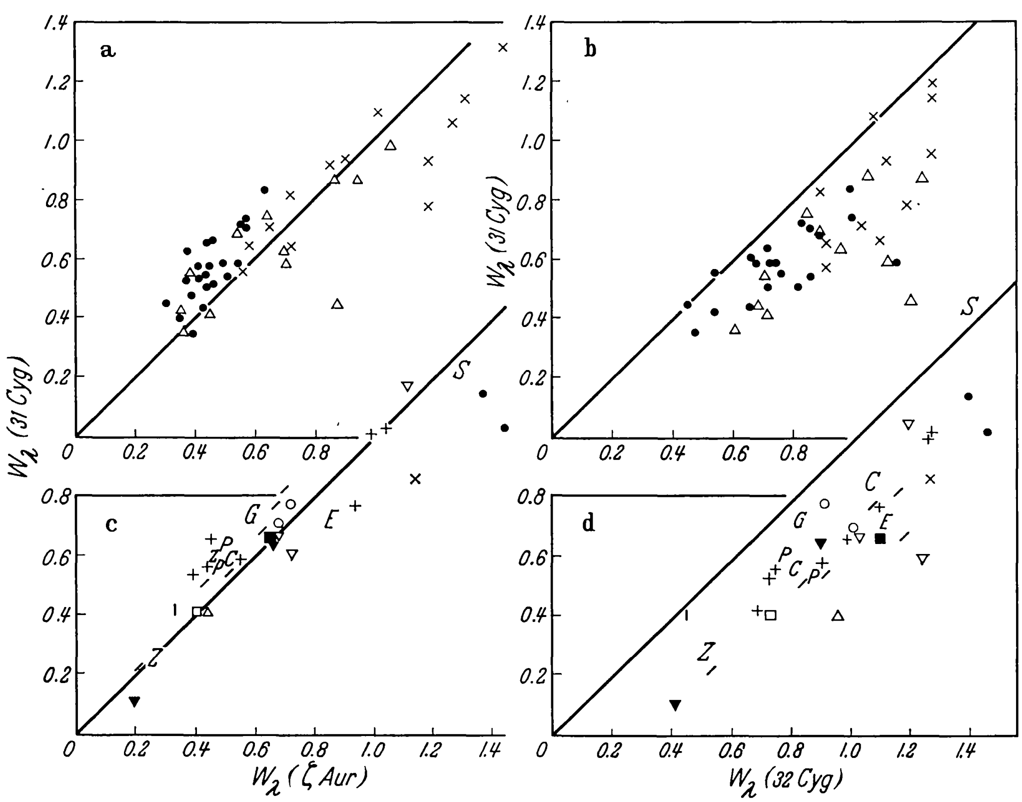

Fig. 1a and b. Comparison of the FeI line intensities of 31 Cyg with ζ Aur (a) and 32 Cyg (b): x, E.P. between 0 and 1.5 eV; △, 2—2.8 eV; ● 3—3.6 eV. Comparison of the other lines of 31 Cyg with ζ Aur (c) and 32 Cyg (d): x Hδ; ○ MgI; △ CaI; □ ScI; ■ ScII; ▽ TiI; ▼ TiII; / VI; ● CrI; + MnI; C CoI; S SrII; Z ZrII; | CeII; P PrII; E EuII; G GdII

2. Line intensities and curves of growth

Fig. 1 gives a comparison of the equivalent widths of the three stars. Obviously the lines of 32 Cyg are almost all stronger than those of 31 Cyg and ζ Aur. The latter two stars have nearly the same line strengths. However, there is a tendency for the relatively weaker FeI lines to be more intense in 31 Cyg and 32 Cyg than in ζ Aur and for the strongest FeI lines to be more intense in ζ Aur than in the other two

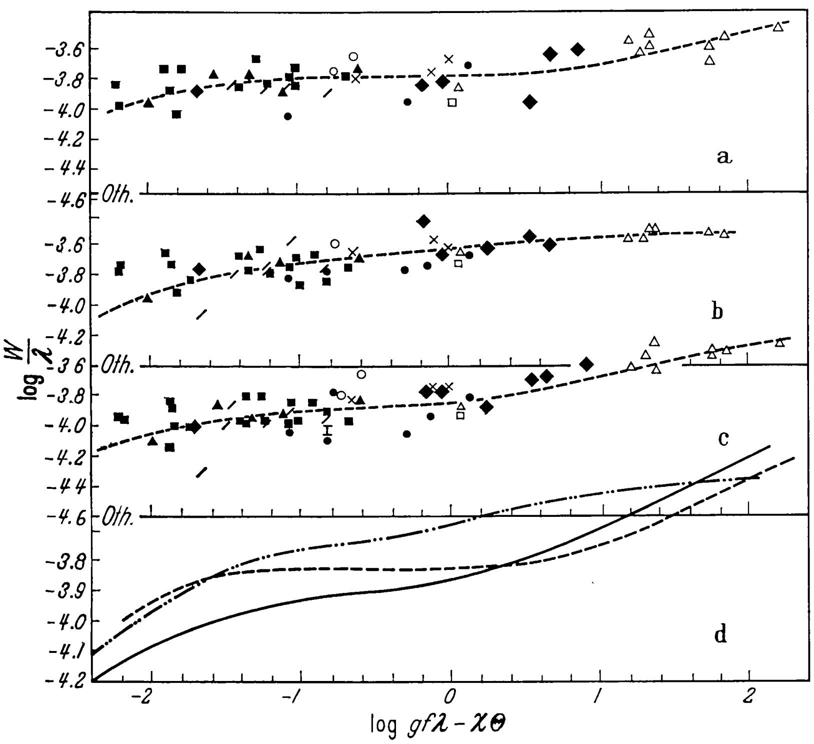

Fig. 2a—d. Curve of growth for the FeI lines for 31 Cyg (a), 32 Cyg (b), ζ Aur (c). The meaning of the symbols is the following: ○, E.P. 0.0 eV; ×, 1.0; △ 1.5; □ 2.2; ◆ 2.4; ● 2.8; / 3.0; ▲ 3.2; ■ 3.4; I 3.6. In (d) the three curves of growth are compared. Full line (ζ Aur); broken line (31 Cyg); line and dots (32 Cyg). (Here a double scale is used for the ordinates)

stars independently of the excitation potential. A better interpretation of the line intensities can be attempted through the study of the curve of growth. A sufficient number of the lines which are not appreciably blended is available only for FeI. The log W/λ have been plotted versus log $gf\lambda - \chi\theta$ where the gf values are those given by Corliss and Warner (1964), χ is the excitation potential and $\theta = 5040/T$ has been taken equal to 1.4 for all three stars (Fig. 2). Curves of growth have been constructed also for $\theta = 1.6$ and $\theta = 1.25$, but they give a larger scattering of the points around the average curve. We have assumed $\theta = 1.4 \pm 0.05$ and $T = 3600°$ K.

From the comparison of the three curves of growth it follows that 32 Cyg has higher microturbulence and lower damping, ζ Aur has the opposite characteristics and 31 Cyg is in between. A comparison with the theoretical curve by MENZEL gives the values of v and Z shown in Table 2, where v and Z are correlated to the microturbulence ξ and to the damping constant Γ by the equations

$$v = \sqrt{\frac{2RT}{\mu} + \xi^2}\,, \qquad Z = \frac{\Gamma c}{\nu v}\,.$$

Table 2. *Damping and microturbulence for the* Fe I *curves of growth of* ζ Aur, 31 Cyg *and* 32 Cyg

	ζ Aur	31 Cyg	32 Cyg
v	7.6	8.3	12.0 km/sec
Z	$10^{-2} > Z > 10^{-3}$	$\sim 10^{-3}$	$< 10^{-3}$

3. Dependence of α upon λ

We have collected the values of $\alpha = I_{cB}/I_{cK}$ measured by different authors (Table 3) for ζ Aur, 31 and 32 Cyg. Fig. 3a gives $m_K - m_B = 2.5 \log \alpha$ versus $1/\lambda$ using only the measurements by WRIGHT (1952)

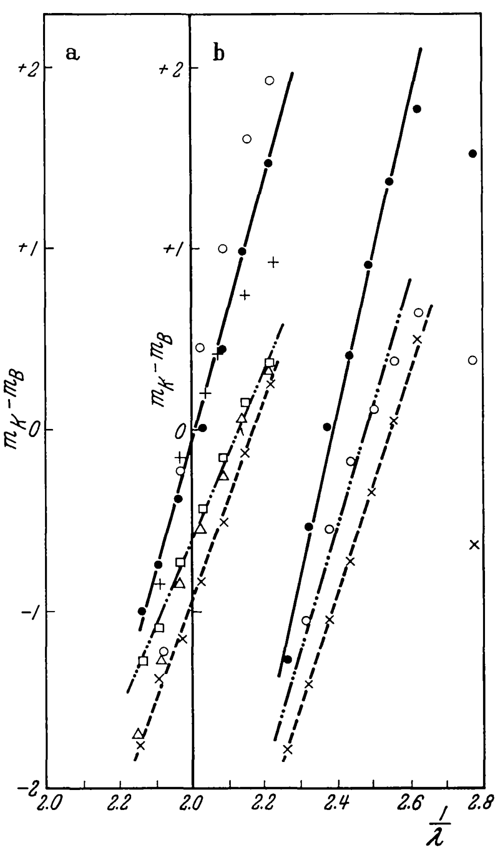

Fig. 3a and b. $m_K - m_B$ versus $1/\lambda$ (data by WRIGHT and LEE): ● —, ζ Aur: × — —, 31 Cyg; □ — ·· —, 32 Cyg; data by FARAGGIANA et al.: ○, ζ Aur; +, 31 Cyg; △, 32 Cyg), (a); $m_K - m_B$ versus $1/\lambda$ (average values): ● —, ζ Aur; ○ — · · —, 31 Cyg; × ——, 32 Cyg, (b) resp. WRIGHT and LEE (1959, 1960) (obtained with higher dispersion than the others) and our results obtained with 22 A/mm. Fig. 3b gives the same relation derived by averaging the data of all the observers. In every case the slope of the straight line for ζ Aur is greater. This slope is proportional to $(1/T_K - 1/T_B)$ where T_K and T_B are the color temperatures of the K-type and B-type components. However, the values of T_K derived from the observations, assuming $T_B \geqq 10000°$ K, range between 2000 and 2500° K for ζ Aur and between 2500 and 3000° K for 31 and 32 Cyg (using the data by WRIGHT and LEE). These excessively low temperatures, compared to those indicated by the line and band spectra, are probably not due to interstellar reddening alone but to the depression of the continuum of the K star by the overlapping absorption lines. I_{cK} is actually the intensity of a pseudo-continuum which differs from the true continuum more and more as λ decreases.

Table 3. $\alpha = I_{cB}/I_{cK}$ *measured by different authors*

λ	ζ Aur (1)	(2)	(3)	(Mean)	31 Cyg (4)	(5)	(Mean)	32 Cyg (6)	(7)	(8)	(Mean)
4400	0.40	0.50	0	0.30	0.20	0.10	0.15	0.30	0.20	0.06	0.19
4300	0.50	0.98	0.32	0.60	0.28	0.46	0.37	0.38	0.32	0.10	0.27
4200	0.70	1.48	0.82	1.00	0.34	0.86	0.60	0.50	0.46	0.16	0.37
4100	0.84	2.00	1.50	1.45	0.46	1.22	0.84	0.66	0.60	0.26	0.51
4000	1.56	2.80	2.52	2.29	0.62	1.56	1.09	0.86	0.80	0.48	0.71
3900	2.50	4.20	4.32	3.67	0.90	1.96	1.43	1.12	1.06	0.96	1.05
3800	4.00	5.60	6.00	5.20	1.26	2.34	1.80	1.40	1.36	2.00	1.59
3600			4.06	(4.06)		1.40	(1.40)		0.55		(0.55)

(1) LEE and WRIGHT (1960); (2) CHRISTIE and WILSON (1935); (3) FARAGGIANA (1965); (4) WRIGHT and LEE (1959); (5) FARAGGIANA and HACK (1963); (6) WRIGHT (1952) (α derived by comparing the B + K spectrum with γ Dra, K5); (7) FARAGGIANA et al. (1965); (8) WELLMANN (1957).

The apparently lower temperature of ζ Aur, which is not confirmed by the behavior of the line spectrum, is probably due to greater overlapping of the absorption wings. This hypothesis is confirmed by Fig. 4, which gives the relation between the half-widths of the lines $\Delta\lambda$ and the central depths R_c measured on our spectrograms. ζ Aur has broader lines than the other two stars. This means that ζ Aur has either a higher macroturbulence or a greater rotational velocity. The instrumental broadening however is too important at our relatively low dispersion to allow a quantitative measurement of this velocity. Since ζ Aur has the lowest microturbulence of the three stars it seems more probable that the broadening of the lines is due to rotation rather than macroturbulence. This alternative is confirmed by the behavior of the chromospheric lines at the beginning and at the end of totality. In the case of ζ Aur the chromospheric lines are red-shifted before and violet-shifted after totality, although the red-shift is smaller than the violet-shift. In 31 and 32 Cyg on the contrary, the lines are violet-shifted both before and after totality. This behavior can be explained by assuming that in

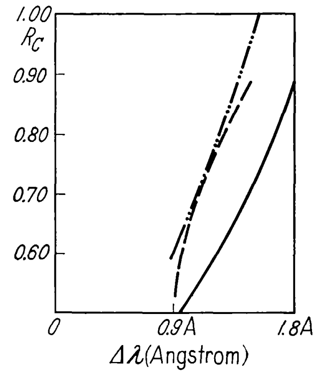

Fig. 4. Half-widths versus central depths: full line, ζ Aur; broken line, 31 Cyg; line dan dots, 32 Cyg

ζ Aur rotation, in the same sense as the orbital motion, as well as downward motions of clouds in the extended atmosphere contribute to the observed shift of the chromospheric lines, while in 31 and 32 Cyg only the second kind of motions is important.

References

Christie, W. H., and O. C. Wilson: Astrophys. J. **81**, 426 (1935).
Corliss, C. H., and B. Warner: Astrophys. J. Suppl. 8, 395 (1964).
Faraggiana, R.: Z. Astrophys. **62**, 99 (1965).
—, A. Gökgöz, M. Hack, and I. Kendir: Mem. Soc. Astron. It. **36**, 63 (1965).
—, and M. Hack: Mem. Soc. Astron. It. **34**, 359 (1963).
Lee, E. K., and K. O. Wright: Publ. Dom. Astrophys. Obs. Victoria **11**, 339 (1960).
McKellar, A., and R. M. Petrie: Publ. Dom. Astr. Obs. Victoria **11**, 1 (1958).
Wellmann, P.: Astrophys. J. **126**, 30 (1957).
Wright, K. O.: Publ. Dom. Astr. Obs. Victoria **9**, 189 (1952).
—, and E. K. Lee: Publ. Dom. Astr. Obs. Victoria **11**, 59 (1959).

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