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ATMOSPHERIC ECLIPSING BINARY ZETA AURIGAE IN THE 1987-1988 ECLIPSE (II)[1]

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ABSTRACT

UBV observations at Yonsei University Observatory (500 and 537 observations each at Ilsan Station and at Campus Station) were made for the latest eclipse of ζ Aur in 1987-1988. Orbital period of Saijo and Saito has been confirmed and the light and color variations on the night JD 244730 are found.

I. INTRODUCTION

The present author has already reported the radius variations of K supergiant component of ζ Aur to the IAU Symposium No.151 (hereafter refered as Paper I) using observations made at Yonsei University Observatory for the 1987-1988 eclipse. With the same data the orbital period and the light and color variations are investigated here as a part of continuation of the Paper I.

A detail description about ζ Aur ($V_{max} = 3.72$, Sp = K4Ib + B7V, P = 972 days = 2.66 years) including results of investigations of photometry, spectroscopy, and model calculations has been give by Sahade and Wood (1978).

II. TIMES OF MINIMUM LIGHT AND THE ORBITAL PERIOD

As was given in Paper I, the most intensive photometric observations of ζ Aur in the past were made in every 8 years which are equivalent to three orbital revolutions of this binary system when a B-type secondary star is eclipsed by the extended atmosphere of K supergiant in a favorable season of the year; for instances, Kron(1940), Christie(1940), and Roach(1941) for the 1939-40, Pettit(1948) and Wood(1951) for the 1947-48, Grant and Abt(1959) and Tanabe and Nakamura(1957) for the 1955-56, 0'Connell(1964), Shao(1964), Zhang and Liu(1965), and Kiyokawa(1967) for the 1963-64, Koyokawa et al.(1972), Sanwal et al.(1973), and Lovell and Hall(1973) for the 1971-72, and Guo *et al.*(1981) for the 1979-80 eclipses.

The depths of the primary minimum light of ζ Aur in *V* is very shallow, only about one tenth of a magnitude, and thus the determination of minimum times are usually made by *B* and *U* light curves whose depths are deeper, about 0.6 mag in *B* and about 2 mag in *U*. The accuracies of the epochs of minimum time and the orbital period determined thereby

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are comparable to most of other short period eclipsing binaries.

The most recent determinations of the orbital period are $972^d.164$ (Kiyokawa 1967), $972^d.160$ (Saijo and Saito 1978) and $972^d.176$ (Guo *et al.* 1981). Among these $972^d.160$ by Saijo and Saito satisfies recent observations better than other two periods. Collection of times of minimum light is listed in Table I. The third column of this table represents residuals computed with light elements by Saijo and Saito,

$$Min\,I = JDHel\ 2427692.825 + 972^d160E. \quad (1)$$

But the present investigation improved slightly as

$$Min\,I = JDHel\ 2427692.845 + 972^d1577E, \quad (2)$$

Table I List of mid-eclipse times of ζ Aur

Time of minima JD 2400000+	E	O-C_1 (day)	O-C_2 (day)	Reference
27692.93	0	+0.09	+0.08	Beer(1934)
27692.70	0	−0.13	−0 15	Christie and Wilson(1935)
27692.70	0	−0.13	−0 15	Oosterhoff(1935)
27693.10	0	+0.27	+0 25	Huffer(1935)
29637 10	2	−0 05	−0.06	Roach(1941)
29637 18	2	+0 03	+0 02	Christie(1940)
32553 65	5	+0.02	+0 02	Pettit(1948)
32553.666	5	+0.041	+0.037	Wood(1951)
35470.025	8	−0.080	−0 071	Tanabe and Nakamura(1957)
38386.51	11	−0.08	−0.05	Hardorp *et al.*(1966)
38386 525	11	−0 060	−0 038	Kitamura(1974)
38386.64	11	+0.05	+0 08	Kiyokawa(1967)
44219.643	17	+0 098	+0.145	Guo *et al.*(1981)
45191 21	18	−0.50	−0 44	Fernandes(1982)
47135.95*(U)*	20	−0.07	−0.02	Nha (this paper)
47135.00*(B)*	20	−0 02	+0.03	Nha (this paper)

and the residuals are given in the fourth column. In this determination, JD 2445191.21 by Fernandes was excluded because of its large residual, but the remaining epochs were all treated with equal weight. The *O-C* diagram of ζ Aur made by Eq. 2 is given in Figure 1. In this diagram 15 data points show a large scatter. Nevertheless, there seems no indication of period variation in the time span of more than 50 years from 1934 to 1987. The orbital period of $972^d.1577$ obtained in this study is essentially same with $P=972^d.15$ by Swope(1935) for seventeen eclipses from 1892 to 1934. Therefore, the orbital period of ζ Aur has been remained unchanged for nearly one century.

III. LIGHT FLUCTUATIONS AND COLOR VARIATIONS OF K SUPERGIANT

Not long ago, Kiyokawa(1967) has reported the light variations of the K component of ζ Aur of the order of several hundredths of a magnitude over several tens of days, and found the gradual light increase with some fluctuations of short periods during the totality of the 1963-64 eclipse. For later eclipses, on the other hand, Saito *et al.*(1978) found that ζ Aur was brighter after the eclipse than before the eclipse by about 0.02 mag in all *UBV*, but argued the 262-day period light variation as a result of pulsation of the K star proposed by Saijo and Saito(1978). They have reached to a conclusion that it seems to be due mainly to the distortion effect (Hutchings and Wright 1971) rather than due to intrinsic variations of K star.

During the total eclipse we see K supergiant only. Therefore, the magnitudes and colors of the totality during each eclipse do represent this star, and they are 7.33, 5.61 and 3.85 for the *U*, *B*, and *V*, respectively, for the 1987-1988 total eclipse and, thus, colors are *U-B*= +1.72 and *B-V*= +1.76. These *UBV* magnitudes and colors are compared with those of previous eclipses. Standardized *UBV* and colors of ζ Aur are available since the 1955-56 eclipse, and these with mean values for some eclipses are listed in Table II and plotted in Figures 2 and 3. Data for the year 1963-64 of this table are the reprodution from Kiyokawa(1967). We see that the cycle-to-cyele variations of *V* light are insignificant, whereas *B-V* changes with time towards larger value and *U-B* with no definate trend. Therefore, a suggestion of a variation of surface temperature of K star by Saijo and Saito (1978) could be accepted as a tenable hypothesis if one assume that more complexities in the latest two eclipses were to be originated on the star's surface but not in other sources. Yet, the large change of average values of *U* and thus *U-B* in Figures 2 and 3 of the 1987-88 eclipse will remain unexplained.

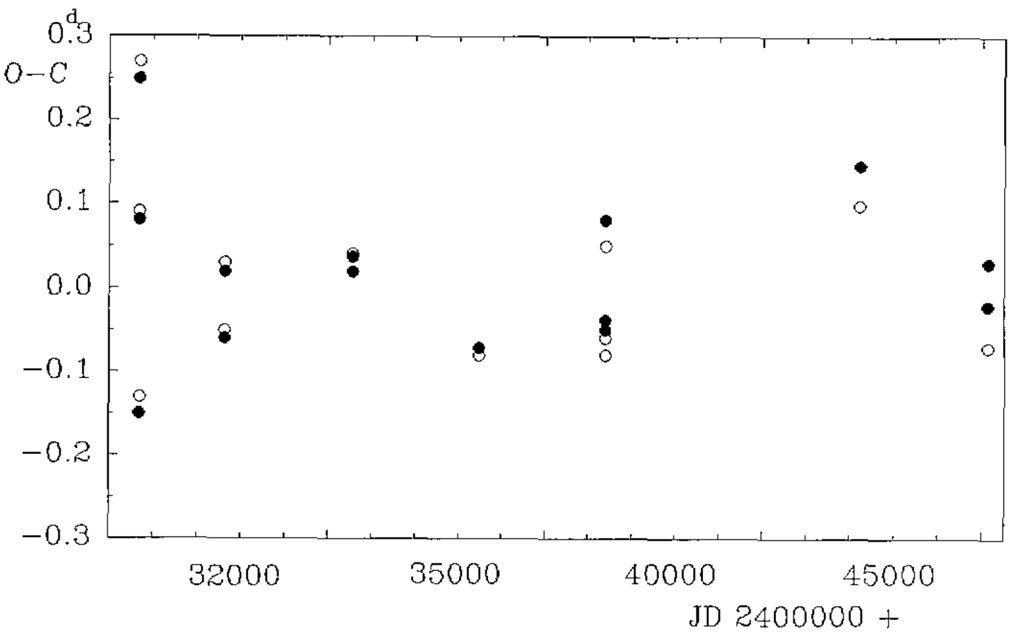

Figure 1 The *O-C* diagram of ζ Aur by the light elements given in Eq 2.

Table II. *UBV* and colors of the K supergiant of ζ Aur

Year	*U*	*B*	*V*	*U-B*	*B-V*	Reference
1955-56	7.36	5 55	3.90	+1.81	+1 650	Kiyokawa (1967)
1963-64	7.382	5 604	3.905	+1.778	+1.699	
	7.32	5 54	3 90	+1.78	+1 64	
	7.38	5.55	3.89	+1.83	+1.66	
	7.33	5.53	3.88	+1.80	+1.65	
	7.36	5.55	3.91	+1.81	+1.64	
mean	7.348	5.544	3.894	+1.804	+1.650	Kiyokawa (1967)
1971-72	7 40	5.51	3.87	+1.89	+1 64	Sanwal *et al.*(1973)
	7.652	5 707	3.947	+1.945	+1.760	Kiyokawa *et al.*(1972)
	7.505	5.643	3 91	+1.862	+1.733	Lovell and Hall (1973)
mean	7.519	5.620	3.909	+1.899	+1 711	
1979-80	7.51	5.58	3.89	+1.93	+1 69	Guo *et al.*(1981)
1987-88	7.33	5.61	3.85	+1.72	+1.76	Nha (this paper)
	7.478	5.691	3.968	+1.787	+1.723	Asonuma *et al.*(1988)
mean	7 404	5 651	3.909	+1.754	+1 742	

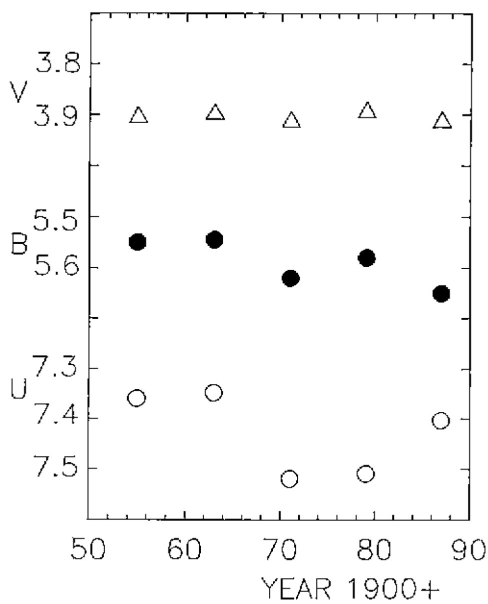

Figure 2. The *UBV* magnitudes of ζ Aur during the totality in different eclipses

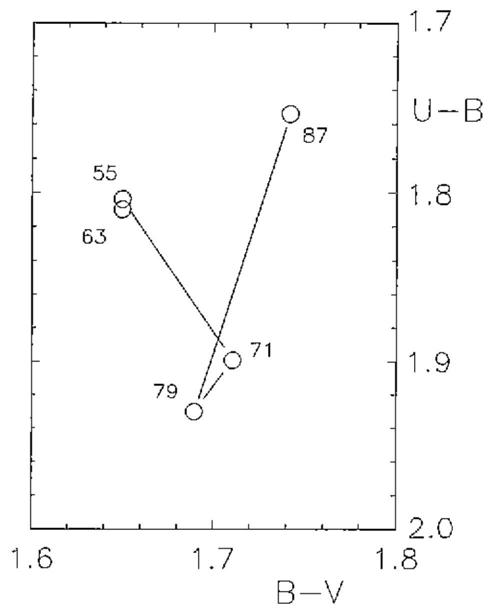

Figure 3. Colors of ζ Aur in each eclipse

As was mentioned in the Paper I, no significant secondary light variations are noticed in the light curves of ζ Aur. Not only with data points in Figure 1 of Paper I, which are mostly averages of 2-3 observations of each night, but the individual observations on some long nights also show straight line distributions as are shown in Figure 4 below for two nights of ten days apart, JD2447121 and 2447131. However, ζ Aur behaved something different on JD2447130 and the light variations are totally unexpected way as shown in the same figure.

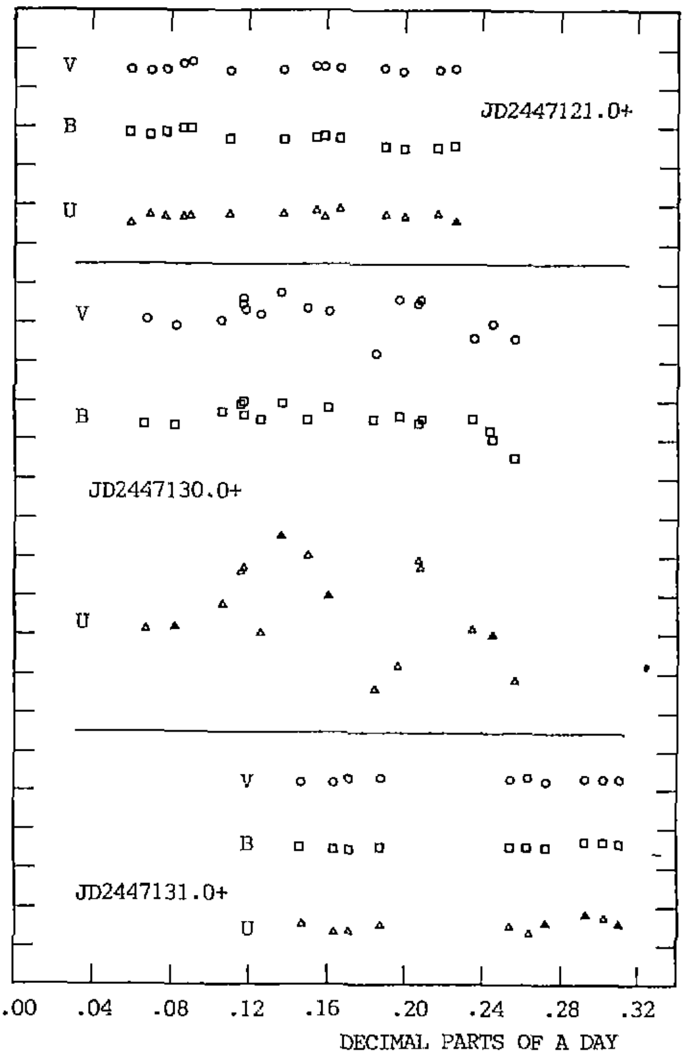

Figure 4. The *UBV* light curves of ζ Aur (from bottom to upwards) during the totality for three long nights. Magnitude scale is 0.1 mag between tick marks.

The pattern of light variations for V and B on this particular night looks alike but not with U whose amplitude of the variations was large, about 0.5 mag.

IV. DISCUSSIONS AND CONCLUSIONS

The present observations show that ζ Aur has had no secondary light variation before, during, and after the eclipse except on one night JD2447130, which was near the mid-eclipse, JD2447135.975. During the eclipse in 1987, observations are made for 21 nights (see Table I) at Ilsan Station alone, and thus the one out-of 21 nights implies that the K supergiant of ζ Aur is optically stable and the brightness change may be on rare occassions compare to that of 95.5 day secondary light variations of Eps Aur (Nha *et al.* 1991).

The well observed five eclipses, once in every 8 years, since the 1955-56 are availadle for the search of a secular variation of the brightness and colors of K supergiant. Saijo and Saito (1978) has summarized the first three eclipses and made a conclusion that the K star had lower luminosity and redder colors in the 1971-72, as compared with the other two eclipses. They have interpreted these with the lower surface temperature of K star in 1971-72. Saijo and Saito, unfortunately, were not aware of the fact that brighter magnitudes and smaller values of colors of K star in the same year were made by Sanwal *et al.* (1973). With these values the mean magnitudes show higher luminosity than those plotted (see Figure 6 of Saijo and Saito). There seems no clear correlation between V magnitudes and color variations with the observations for the 1979-80 and for the 1987-88 eclipses, and the unusual color variations of two latest eclipses are left unexplained.

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REFERENCES

Asonuma, A., Nishida, S., Okumura, S., Shimada, M., Ueda, Y., Watanabe, T., and Saito, M. 1988, IBVS 3180.

Beer, A. 1934, MNRAS, 95, 24.

Christie, W. H. 1940, ApJ, 92, 392.

Christie, W. H. and Wilson, O. C. 1935, ApJ, 81, 426.

Fernandes, M. 1982, BAV, 31(4), 75.

Grant, G. and Abt, H. A. 1959, ApJ, 129, 320.

Guo, Z.-h., Jia, G.-S., and Liu, X.-f. 1981, Chinese A&Ap, 5, 406.

Hardorp, J., Herczeg, T., and Scholz, M. 1966, ZAp, 64, 97.

Huffer, C. M. 1935, ApJ, 81, 292.

Hutchings, J. B. and Wright, K. O. 1971, MNRAS, 155, 203.

Kitamura, M. 1974, Ap&SS, 28, L17.
Kiyokawa, M. 1967, PASJ, 19, 209.
Kiyokawa, M., Kitamura, M., Saito, M., Sato, H., Sato, N., and Ogata, H. 1972, Tokyo Astr. Bull. No. 221, 2577.
Kron, G. E. 1940, PASP, 52, 124.
Lovell, L. P. and Hall, D. S. 1973, PASP, 85, 131.
Nha, I.-S., Kim, H.-I., Lee, Y.-S., and Jeong, J. H. 1991 (in press).
O'Connell, D. J. K. 1964, Ricerche Astr. Specola Vaticana, 5, 523.
Oosterhoff, P. Th. 1935, ApJ, 81, 461.
Pettit, D. 1948, PASP, 60, 102.
Roach, F. E. 1941, ApJ, 93, 1.
Sahade, J. and Wood, F. B. 1978, Interacting Binary Stars (Pergamon Press: New York), pp. 120-124.
Saijo, K. and Saito, M. 1978, Ann Tokyo Astr. Obs., 17, 110.
Saito, M., Sato, H., and Saijo, K. 1978, Ann. Tokyo Astr. Obs., 17, 105.
Sanwal, N. B., Parthasarathy, M., and Abhyyanker, K. D. 1973. Observatory, 93, 30.
Shao, C. Y. 1964, AJ, 69, 858.
Swope, H. H. 1935, HCOC, No. 399.
Tanabe, H. and Nakamure, T. 1957, Tokyo Astr. Bull., No. 96, 1023.
Wood, F. B. 1951, ApJ, 114, 505.
Zhang, H.-z. and Liu, X.-f. 1965, Acta Astr. Sinica, 13, 97.