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THE 1937 ECLIPSE OF ζ AURIGAE (*)

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SVMMARIVM. — Auctor instituit investigationem spectro-photometricam stellae duplicis ζ Aurigae, ante et post eius eclipsin inchoatam d. 21 Aprilis anni 1937. Ad quem finem usus est imaginibus obtentis in Specula Vaticana, auxilio refractoris photographici superposito prismate obiectivo cum crate.

ζ Aurigae is known as one of the most interesting eclipsing binaries. We need not repeat here the history of the star, which is given in detail in some of the papers quoted below. The binary which consists of a B8- and a K5- component has a period of $972.^d2$. It was in 1932, when the eclipse of the B-type companion by the K-type primary was observed by GUTHNICK and SCHNELLER (1) and by HOPMANN (2), the first time after the prediction by BOTTLINGER (3). On account of the rather incomplete material then available the results obtained could be only preliminary. The next minimum in 1934 being the subject of an extensive and thorough study by the same and other observers provided a very interesting account of the various phenomena connected with the eclipse of the star (4).

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(1) « Sitzber. Preuss. Akad. », 1932, p. 1.

(2) « Verh. Leipzig Akad. », 85, 117, 1933.

(3) A. N. 226, 239, 1926.

(4) GUTHNICK, SCHNELLER and HACHENBERG, « Sitzber. Preuss. Akad. » 1925, p. 1. CHRISTIE and WILSON, Ap. J. 81, 426, 1935. BEER, M. N. 95, 24, 1934. SMART and GREEN, M. N. 95, 31, 1934. OOSTERHOFF, Ap. J. 81, 461, 1935. HUFFER. Ap. J. 81, 292, 1935.

The beginning of the next minimum of ζ Aurigae was due in April, 1937. Although the observational conditions were unfavorable the star being low in the west it seemed worthwhile to secure some new material.

The equipment of the Vatican Observatory, where an astrographic telescope, 2 large objective prisms and an objective grating were available, suggested a spectrophotometric study of the star. From April 15 to April 28 eight plates were obtained. Table I shows the times of midexposure of the different plates, the exposure times lying between 40^m and 1^h.

TABLE I. — *Dates of Plates.*

Plate Nr.	Midexposure	Plate Nr.	Midexposure
1	April 15.85 U. T.	5	April 21.83 U. T.
2	16.84	6	22.83
3	17.82	7	23.83
4	20.81	8	28.83

The 1937 eclipse was expected to start on April 21. For this reason plate 5 seems to be of especial interest the more so, as most of the other observers were prevented by bad weather from observing this critical phase. Also in Castel Gandolfo the sky did not clear up until after sunset and just permitted one plate to be taken.

The plates were obtained with the 40 cm Zeiss Astrograph (focal ratio 1:5) of the observatory and with two objective prisms of 4° and 8° refracting angle respectively (aperture 60 cm). The two objective prisms were used together yielding a dispersion of 90 angstroms per millimeter near H_γ. The range of wavelength in good focus extended from about H_γ to H_ζ.

Since the telescope gave images of good definition over a large field, 30 cm/30 cm plates (Matter Sternplatten) could be used, and the spectra of λ Aurigae and of a number of suitable comparison stars (λ Aur, η Aur, ρ Aur, BD + 41°1044) could be taken at the same time on the same plate.

The grating crossed by prism method served to provide the photometric scale. The grating used for all plates had the geometric constant of 1.50 millimeter. The breadth of the grating wires being very exactly the same as the free space intervals between the wires, the photometric constant $(m_1 - m_0)$ becomes correspondingby $0^m.98$.

The spectra were run through the Zeiss recording microphotometer of the observatory. On account of the grating each star spectrum consists of a central spectrum and two curved side spectra. The tracings of these three spectra were made on the same sheet of paper (1). The central and side spectra of the different stars, when compared with each other provided the characteristic curves (2).

The intention was to measure the intensity of the continuous background of ζ Aurigae at certain wavelengths and at the same time to add some information about the behaviour of the K line, which is produced in the envelope of the K5 primary.

Regarding the first point it was rather difficult to find wavelengths, where the continuous spectrum was not too much disturbed by absorption lines. One has to remember that the star during minimum is of type K5. The following six wavelengths were chosen:

3915, 4020, 4065, 4160, 4210, 4365 angstroms.

Table II shows the results of the photometric procedure described above. It gives the magnitude differences between ζ Aurigae and λ Aurigae, the main comparison star, for 6 days. The plates of April 15 and April 22, which are not so good as the others, are here omitted.

(1) I should like to express my best thanks to P. Junkes for his kindness to repeat some of the tracings at a time, when I had left Castel Gandolfo.

(2) Cf. e. g. Öhman, *Dissertation*, 1930.

TABLE II. — *Magnitude differences.* ζ Aur − λ Aur.

Nr.	Date	λ 3915	λ 4020	λ 4065	λ 4160	λ 4210	λ 4365
2	April 16	− $^{\mathrm{m}}$.15	− $^{\mathrm{m}}$.10	− $^{\mathrm{m}}$.09	$^{\mathrm{m}}$.00	$^{\mathrm{m}}$.00	− $^{\mathrm{m}}$.33
3	17	.14	.10	.05	.00	− .10	.23
4	20	.10	.12	.07	+ .04	.08	.50
5	21	.10	.00	.06	− .04	.09	.40
7	23	+1 .70	+ .95	+ .95	+ .63	+ .47	.00
8	28	1 .83	1 .09	0 .94	.72	.47	+ .15

Looking at the data for the critical 21st of April we get as a first result from this table, that ζ Aurigae was certainly not yet then at minimum. The table values for April 21 are the same as for preceding days. A second point would be to see, whether the partial eclipse of the B8 companion by the K5 primary had already started at our time of observation. GUTHNICK and SCHNELLER (1) have found, that the partial eclipse began on April 21.60 (2). In this case we should expect a change of $0^{\mathrm{m}}.4$ in the magnitude differences for λ 3915 between April 20 and April 21, the value of $0^{\mathrm{m}}.4$ following from GUTHNICK, SCHNELLER and HACHENBERG's light curve (3), if we adapt their amplitude to that of the present violet differences $1^{\mathrm{m}}.83$. The probable error of our observations being not larger than $\pm 0^{\mathrm{m}}.10$ we find, that the present results do not confirm those of GUTHNICK and SCHNELLER. According to the present data the beginning of the partial eclipse, if we really assume, that it had started before the time of our observation, cannot have been earlier than April 21.75. On the other hand

(1) A. N. 262, 429, 1937.

(2) GUTHNICK und SCHNELLER give 21.10 U. T. instead of 21.60. The times of observation quoted by them as 21.316 instead of 21.816 etc. we have added $0^{\mathrm{d}}.5$ to their datum of 21.10.

(3) « Sitzber. Preuss. Akad. », 1935, p. 1.

taking the smallest possible value for the duration of the partial phases ($0^d.8$) the beginning of the partial eclipse must have occurred before April 22.0, plate 6 of our series (April 22.83) showing the star then already in minimum. The photometry confirms therefore a remark in a preliminary note (1), that on April 21 we were observing the star immediately before or just at the beginning of its partial eclipse.

We used already the mean magnitude difference between maximum and minimum for λ 3915. Table III gives the amplitudes A for different wavelengths and shows, how the combination of a B8 and a K5 component makes them rapidly decrease going from the violet to the red.

TABLE III. — *Amplitudes for different wavelengths.*

Spectrophotometric values		Values obtained from photographs on different kinds of plates and from photoelectric observations (2)	
λ	A	λ	A
3915	$1^m.89$	3900	$1^m.76$
4020	1 .10		
4065	1 .01	4140	1 .03
4160	0 .68	4180	0 .92
4210	0 .54	4300	0 .76
4365	0 .45	4410	0 .60

As was to be expected the spectrophotometric values show an even steeper gradient than those, which are derived from direct photographs or from photoeletric measurements and which are given in the 3rd and 4th column of the table according to material in the paper by GUTHNICK, SCHNELLER and HACHENBERG (2).

(1) A. N. 6277, 1937.
(2) « Sitzber. Preuss. Akad. », 1935, p. 14.

The data for April 23 or 28 give at once the magnitude difference between the K5 component, which is only visible during minumum, and λ Aurigae. Connecting these values with those of earlier days, when the combined light of the B8 and the K5 component is observed, we derive at the same time the magnitude difference between the B8 component and λ Aurigae. One further step gives the magnitude difference between the two components of the binary (see Table IV).

TABLE IV. — *Magnitude difference between the two components of ζ Aurigae.*

λ	$m_K - m_B$
3915	$+1^m.68$
4020	0 .61
4065	0 .48
4160	-0 .17
4210	0 .48
4365	0 .75

The data of table IV allow us to derive the gradient of the continuous spectrum of the K5 component relative to that of the B8 star. This gradient is defined by:

$$\Phi_{KB} = 0.92 \times \frac{d}{d\,{}^1/_\lambda}\,(m_K - m_B).$$

Omitting the $(m_K - m_B)$ value for λ 3915, where the continuous spectrum of the K5 star is very greatly disturbed by absorption, the relation between the $(m_K - m_B)$ and ${}^1/_\lambda$ can be represented approximately by a linear function. The value of Φ_{KB} becomes so 7.4. If we introduce the relation between gradient and colour temperature and use 18000° as the approximate temperature of the B8 companion, the given value of the relative gradient leads to a colour temperature of about 1700°

for the K5 primary. This low value is in agreement with the result of CHRISTIE and WILSON (1), who found the temperature of the K5 component of the order of only 1500° assuming the temperature of the B8 star to be between 15000° and 20000°. But this similarity of the figures does not mean much more than that the K5 spectrum is extremely weak in the violet, as we should expect in the case of a red supergiant. We have to remember, that our K5 colour temperature refers to the violet region, where the spectra of all K stars show great deviations from that PLANCK distribution, which represents the range of longer wavelengths of their spectra fairly well and provides their normally used colour temperatures. In comparison with these the above derived colour temperature value of 1700° must be too small. GUTHNICK, SCHNELLER and HACHENBERG (2) e. g. get 3160° as final temperature value for the K5 star using the spectral range from λ 4600 to λ 5800, while their corresponding « violet temperature » is only about 2200°–2300°.

For the reasons stated, that the derived « violet » colour temperature does not represent well enough the effective temperature wanted, we can not use that colour temperature for the derivation of the radii ratio of the two components. As a simple calculation shows our data would lead to a very small value of k of the order of magnitude of 10^{-4}.

We come now to the study of the chromospheric K line, which is produced in the envelope of the K5 star. Our plates show the line from April 15 onwards (3). On all the plates the line appears broader than its chromospheric character would lead us to expect. A determination of the equivalent widths was made (these expressed in angstroms) for the days of April 15 to 21. In order to take into acconnt the existence of the normal K line, produced in the K5 star atmosphere and rather faint in the composite (B8 + K5) spectrum the plate of April 28 was used. From this the equivalent width of the normal line K_K was derived. Measuring the equivalent width of the K line in the composite

(1) L. c.

(2) L. c.

(3) According to A. BEER's material obtained at the Solar Physics Observatory Cambridge, the chromospheric line was already present on March 22. I am much obliged to Dr. BEER for having shown me his material before its publication.

spectrum K_{BK} we get the equivalent width of the chromospheric line K_B from the relation [1]:

$$K_B = K_{BK} + I_K/I_B\,(K_{BK} - K_K)$$

In this equation I_K/I_B is the intensity ratio of the continuous spectrum in the K region of the K5 and B8 component. According to the data in table IV this has the value of 0.21

Mostly on account of the difficulty of fixing the position of the continuous background the determination of K_K is not very accurate. The present measurements give a value of 24 angstroms with an error of ± 15 percent, while Christie and Wilson find only 16 angstroms. As the above equation shows, the values of K_B are rather sensitive to the assumed value of K_K. With K_K equal to 24 angstroms our plates give the following values for K_B (see Table V):

Table V. — *Equivalent widths of the chromospheric* K *line.*

Date	E. W. (angstroms)
April 15	1
16	2.2
17	3.5
20	3.5
21	12.1

As our value for K_K exceeds that found by Christie and Wilson, our equivalent widths of the chromospheric line are also nearly twice as large as in corresponding data of the American and Cambridge observers in 1934. This result may be partly due to the fact, that the former observers were using a slit spectrograph, while our own

(1) Cf. Christie and Wilson, l. c.

observations are based on objective prism plates. The objective prism being the most suitable instrument for spectrophotometry of the continuous spectrum, which was our main object, is known to be inferior to a slit spectrograph for determination of line intensities. Although we know from former eclipses that the extent and the gradient of the Ca^+ envelope differs widely at different times, we cannot decide therefore whether the differences in the present case are real. Further material of the 1937 eclipse will have to be awaited. What our data confirm is the steep increase of the K line intensity near total eclipse found by former observers, this result pointing to a steep density gradient for the Ca^+ ions in the inner parts of the K5 envelope.

In conclusion my heartiest thanks are due to P. J. Stein, by whose great personal interest my work in Castel Gandolfo was rendered possible.