THE ECLIPSING BINARY WX ERIDANI

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Abstract. The Algol type eclipsing binary WX Eridani was observed on 21 nights with the 48-inch telescope of the Japal-Rangapur Observatory during 1973–74 and 1974–75 seasons in UBV colors. An improved period of $P = 0\overset{\mathrm{d}}{.}82327038$ was obtained from the analysis of the times of five primary minima. Standstills between phase angles 50–80°, 100–130°, 230–260° and 280–310° were present in the light curves. The analysis of the light curves indicated the eclipses to be grazing with the primary a transit and the secondary an occultation. Elements derived from the solution of the light curve using Russell-Merrill method are given. From the comparison of the fractional radii with Roche lobes, it is concluded that none of the components has filled its respective Roche lobe. The spectral type of the primary component is estimated to be F3 and it is found to be a δ-scuti type variable pulsating with two periods equal to one-fifth and one-sixth of the orbital period.

1. Observations

WX Eridani was reported to be an eclipsing binary of period $0\overset{\mathrm{d}}{.}82326997$ by S. Gaposchkin (1953). Since a photo-electric light curve did not exist for this system, it was placed on the observing programme of the 48-inch telescope (120 cm) of the Japal-Rangapur Observatory. The star was observed on 21 nights during 1973–74 and 1974–75 observing seasons in UBV colors of Johnson's system with an EMI 6256B photomultiplier. BD $-1°482$ and BD $-1°488$ were used as comparison and check stars respectively. From the differences in magnitudes of the check and comparison stars, it was found that the comparison star was constant in brightness during the period of observation. The instrumental system was standardized by observing

TABLE I

Times of primary minima of WX Eridani

Hel J.D.	*E*	(O–C)	References
2427531.687	0	—	Gaposchkin (1953)
2442021.2452	17600	$-0\overset{\mathrm{d}}{.}0005$	Present study
2442035.2405	17617	$-0\overset{\mathrm{d}}{.}0008$	
2442063.2337	17651	+0.0005	
2442356.3196	18007	+0.0027	
2442370.3095	18024	−0.0028	

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a number of standard stars. The magnitude and colors of the comparison star in the standard system are: $V = 8^{m}.981$, $B-V = +0^{m}.445$ and $U-B = -0^{m}.033$. The individual observations were published by Abhyankar *et al.* (1978) who gave the improved ephemeris as

$$\text{Prim. Min Hel. J.D. } 2437531.687 + 0^{d}.82327038E \tag{1}$$

The times of primary minima and $(O-C)$ values derived from the new period are given in Table I.

2. Rectification

Since the ultraviolet observations did not cover all the phases satisfactorily, only V and B light curves, plotted in Figure 1, were used for solution. They show stand-stills

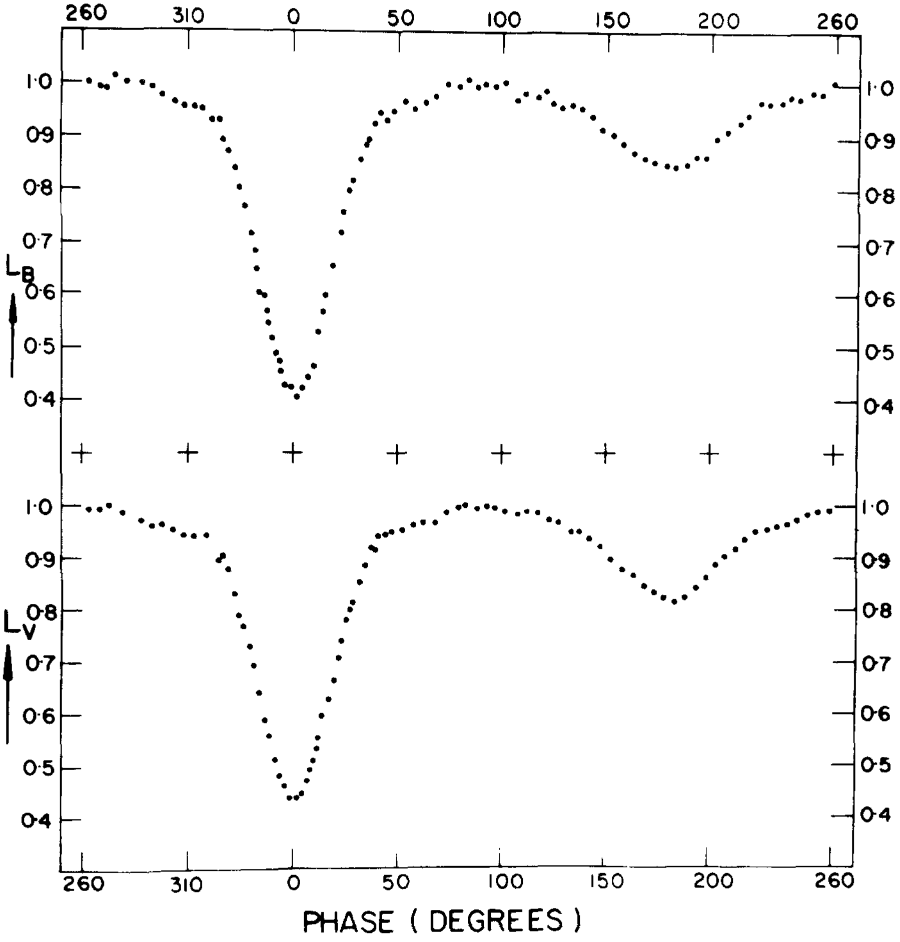

Fig. 1. B and V light curves (normal points) of WX Eridani.

TABLE II

(a) Normal points in yellow

Phase (fraction of period)	*V* (var-comp)	No. of points *N*	Phase (fraction of period)	*V* (var-comp)	No. of points *N*
0.0040	$+0^{\mathrm{m}}390$	2	0.4663	−0.330	6
0.0104	+0.367	2	0.4808	−0.314	5
0.0170	+0.311	2	0.4938	−0.301	5
0.0209	+0.258	2	0.5061	−0.290	4
0.0268	+0.212	2	0.5210	−0.304	5
0.0293	+0.170	2	0.5350	−0.324	8
0.0322	+0.122	2	0.5508	−0.350	5
0.0382	+0.052	3	0.5625	−0.381	5
0.0450	−0.008	2	0.5758	−0.401	5
0.0530	−0.071	1	0.5911	−0.417	3
0.0586	−0.132	2	0.6022	−0.440	3
0.0628	−0.185	2	0.6178	−0.459	4
0.0681	−0.242	2	0.6322	−0.465	3
0.0736	−0.269	2	0.6467	−0.470	4
0.0783	−0.289	2	0.6610	−0.476	3
0.0864	−0.337	4	0.6740	−0.482	4
0.0944	−0.377	7	0.6874	−0.494	3
0.1026	−0.419	4	0.7005	−0.506	4
0.1073	−0.416	3	0.7166	−0.502	3
0.1133	−0.445	5	0.7311	−0.504	4
0.1224	−0.450	2	0.7462	−0.504	3
0.1314	−0.456	8	0.7566	−0.511	3
0.1462	−0.461	9	0.7771	−0.494	2
0.1603	−0.472	6	0.8002	−0.478	4
0.1729	−0.477	5	0.8131	−0.466	4
0.1863	−0.478	6	0.8270	−0.472	2
0.2026	−0.502	4	0.8406	−0.462	2
0.2180	−0.508	4	0.8542	−0.448	3
0.2293	−0.512	2	0.8680	−0.443	3
0.2446	−0.508	4	0.8854	−0.448	2
0.2570	−0.511	3	0.9017	−0.390	2
0.2679	−0.509	4	0.9063	−0.400	2
0.2802	−0.504	2	0.9136	−0.367	3
0.2985	−0.494	3	0.9212	−0.306	3
0.3090	−0.498	2	0.9273	−0.252	2
0.3259	−0.496	4	0.9333	−0.225	4
0.3411	−0.481	6	0.9416	−0.167	2
0.3551	−0.476	8	0.9467	−0.111	5
0.3696	−0.458	7	0.9549	−0.026	3
0.3813	−0.457	7	0.9621	+0.067	5
0.3948	−0.441	6	0.9684	+0.124	4
0.4085	−0.420	6	0.9761	+0.222	3
0.4219	−0.393	3	0.9818	+0.290	4
0.4376	−0.367	4	0.9876	+0.334	2
0.4517	−0.356	5	0.9965	+0.389	1

TABLE II—*Continued*

(b) Normal points in blue

Phase (fraction of period)	B (var-comp)	No. of points N	Phase (fraction of period)	B (var-comp)	No. of points N
0.0035	+0.386	3	0.5219	−0.405	5
0.0110	+0.353	2	0.5351	−0.425	7
0.0186	+0.299	3	0.5492	−0.420	5
0.0241	+0.236	3	0.5631	−0.466	4
0.0312	+0.108	6	0.5768	−0.484	5
0.0377	+0.032	2	0.5919	−0.501	3
0.0416	−0.026	2	0.6047	−0.518	4
0.0511	−0.131	1	0.6188	−0.547	4
0.0610	−0.223	2	0.6330	−0.543	3
0.0658	−0.284	2	0.6474	−0.543	4
0.0731	−0.341	4	0.6593	−0.556	2
0.0794	−0.364	3	0.6731	−0.553	5
0.0872	−0.418	4	0.6882	−0.565	3
0.0946	−0.451	5	0.7014	−0.560	4
0.0998	−0.464	4	0.7173	−0.584	3
0.1068	−0.499	5	0.7323	−0.583	3
0.1145	−0.522	4	0.7455	−0.570	2
0.1231	−0.505	2	0.7548	−0.569	2
0.1319	−0.525	9	0.7651	−0.598	1
0.1467	−0.545	8	0.7793	−0.583	1
0.1600	−0.530	7	0.7986	−0.584	3
0.1734	−0.544	6	0.8126	−0.575	3
0.1864	−0.557	7	0.8253	−0.546	3
0.2033	−0.582	4	0.8415	−0.542	2
0.2174	−0.578	3	0.8550	−0.533	3
0.2286	−0.591	3	0.8687	−0.531	3
0.2421	−0.578	4	0.8815	−0.530	1
0.2535	−0.584	3	0.8924	−0.506	2
0.2662	−0.579	3	0.9010	−0.496	3
0.2796	−0.586	2	0.9071	−0.462	2
0.2962	−0.552	2	0.9142	−0.433	3
0.3055	−0.566	2	0.9219	−0.395	3
0.3226	−0.556	2	0.9280	−0.348	2
0.3307	−0.570	2	0.9336	−0.291	4
0.3419	−0.544	6	0.9425	−0.224	4
0.3553	−0.534	7	0.9472	−0.173	3
0.3684	−0.538	7	0.9514	−0.118	2
0.3813	−0.530	8	0.9573	−0.036	2
0.3957	−0.513	6	0.9599	−0.025	2
0.4093	−0.485	6	0.9624	+0.020	3
0.4228	−0.473	3	0.9672	+0.071	2
0.4383	−0.458	4	0.9701	+0.124	2
0.4524	−0.435	5	0.9768	+0.188	3
0.4660	−0.422	5	0.9808	+0.219	2
0.4800	−0.409	6	0.9844	+0.276	2
0.4944	−0.404	5	0.9887	+0.342	2
0.5060	−0.400	4	0.9969	+0.346	2

on either side of the primary and secondary eclipses at phase angles 50°–80°, 100°–130°, 230°–260° and 280°–310°. The stand-stills were more prominent in blue light than in yellow. The light curves were normalized to unit light intensity at maximum by adding $+0^{\mathrm{m}}.51$ and $+0^{\mathrm{m}}.58$ to yellow and blue magnitudes respectively. The observations were grouped to form normal points given in Table II and plotted in Figure 1.

The light outside the eclipses was Fourier analysed for getting the rectification coefficients. In this analysis, points falling in the region of the stand-stills were not used. The light outside the eclipses was represented by

$$L = \sum_{n=0}^{3} A_n \cos n\theta + \sum_{n=1}^{3} B_n \sin n\theta, \tag{2}$$

and the coefficients were obtained by least squares method. We had also tried to extend the Fourier series up to terms in cos 4θ and sin 4θ. However, their coefficients were found to be too large to be realistic. We believe that these terms arise from the selection of phases used for finding the coefficients.

The rectification coefficients were derived by using the precepts of Russell and Merrill (1952). For the preliminary solution we had assumed a spectral type of A7 for the primary as given in Koch *et al.* (1963) catalogue. However the final solution is based on the spectral type F3 v derived in the present work. Cester's (1969) tables were employed to get the required efficiency factors E_c and E_h. All the derived coefficients are given in Table III.

The light and phases were rectified by using the formulae

$$L_{\mathrm{Rect}} = \frac{L_{\mathrm{obs}} + C_0 + C_1 \cos\theta + C_2 \cos 2\theta - \sum_{n=1}^{3} B_n \sin n\theta - A_3 \cos 3\theta}{(A_0 + C_0) + (A_2 + C_2)\cos 2\theta}$$

and

$$\sin^2 \Theta = \frac{\sin^2 \theta}{1 - Z \cos^2 \theta}.$$

TABLE III

Fourier and rectification coefficients

Coefficient	*V*	*B*
A_0	+0.94975 ± 0.00149	+0.95641 ± 0.00241
A_1	−0.01433 ± 0.00826	−0.01778 + 0.01362
A_2	−0.05005 ± 0.00218	−0.04469 ± 0.00368
A_3	−0.00594 ± 0.00726	−0.00818 ± 0.01212
B_1	+0.00100 ± 0.00124	−0.00165 ± 0.00211
B_2	+0.00244 ± 0.00141	−0.00072 ± 0.00230
B_3	−0.00046 ± 0.00130	−0.00368 ± 0.00219
C_0	+0.01864	+0.02607
C_1	+0.01433	+0.01778
C_2	+0.00611	+0.00855
Z	0.088	0.068

TABLE IV

Preliminary elements from solution of light curves

Element	V curve	B curve
x	0.600	0.800
k	0.707	0.685
α_0^{tr}	0.982	1.0224
α_0^{oc}	0.992	1.0000
$1-l_0^{oc}$	0.109	0.093
$1-l_0^{tr}$	0.480	0.496

3. Solution

As a first step, a plot of L_{Rect} versus $\sin^2 \Theta$ (for normal points) was made and a smooth curve was drawn through them. A preliminary study of this curve indicated the primary eclipse to be transit and the secondary eclipse to be occultation. Assuming different values of k, the ratio of the radii, we obtained α_0^{oc} and α_0^{tr} from the depth relation. For the values of n tabulated in Merrill's (1950) tables χ_n were obtained and used for computing $\sin^2 \Theta_e$ by Wellmann's (1953) method. The least-squares solution is given by

$$\sin^2 \Theta_e = \frac{\sum W_n(\chi_n/\chi_0) \sin^2 \Theta_n}{\sum W_n(\chi_n/\chi_0)^2} \tag{5}$$

where

$$W_n = \left\{\frac{1 - l_0}{2a_0(1 + kp_0)\, \partial p/\partial a}\right\}^2$$

TABLE V

Final elements of light curves

Elements	V	B
z	0.078	0.078
x	0.600	0.800
k	0.698	0.698
$1-l_0^{oc}$	0.110	0.096
$1-l_0^{tr}$	0.476	0.498
L_g	0.890	0.904
L_s	0.110	0.096
α_0^{tr}	1.000	1.000
α_0^{oc}	1.000	1.000
θ^e	42°13′	
J	83°13′	
r_g	0.408	
r_s	0.285	

as given by Kopal (1959). We used both the primary and secondary eclipses together to derive the value of $\sin^2 \Theta_e$. Then k, and $\sin^2 \Theta_e$ gave the desired elements: i, r_g, r_s, L_g and L_s for each assumed k value. These elements were used for computing the theoretical light curve which gave the $(O-C)_i$ for each normal point. A plot of $\sum W_i(O-C)_i^2$ where $W_i = N_i/L_i^2$ against k gave a minimum for a certain value of k which represents the best estimate of k. The results for the two colors are given in Table IV. Since the yellow solution corresponds to a slightly partial eclipse while the blue solution gives a slightly annular eclipse, we adopted a grazing eclipse as the best fit for both the colours. The depths of the eclipses in the hand-drawn curves had to be slightly adjusted for this purpose. A minimum adjustment was made giving the best value of $k = 0.698$. The final adopted elements are given in Table V.

4. Discussion

From the magnitude of the variable at maximum ($V = 8.471$ and $B = 8.846$) and the luminosity of the primary star, its magnitude and colour are found to be $V = 8.567$ and $B-V = 0.360$. This gives a spectral type of F3 to the primary star. Assuming this to be a main sequence star, its absolute magnitude would be $M_v = +3.1$ (Allen, 1973). Comparing the luminosities of the two components we get $\Delta V = +2.6$ (secondary-primary). From this we get $M_v = +5.7$ for the secondary which gives it a spectral type of G8V. The colour of the secondary, $B-V = +0.556$, derived from our luminosities is not reliable as the secondary contributes very little light. Since no spectral studies have been made of this system, reliable spectral types are not available and the above classifications are to be considered as tentative. Taking F3 v and G8 v as the spectral types of the primary and secondary components the mass ratio would be $q = 0.60$. From Plavec's (1964) tables, for this mass ratio, the radii of Roche lobes of the stars are $r_g^* = 0.422$ and $r_s^* = 0.328$. Comparing these values with $r_g = 0.408$ and $r_s = 0.285$ derived from our analysis, we find that none of the components is filling its Roche lobe. WX Eridani seems to be a detached system.

5. Variability of the Primary Component

In Figure 2 we have plotted the rectified normal points and the theoretical light curve (solid line) derived from the elements given in Table V. Regular deviations between the theoretical and observed points can easily be noticed throughout the light curves. The $(O-C)$'s clearly show a wave-like variation with changing amplitude. This indicates that one of the components is variable. Since the deviations are more prominent during the secondary eclipse when the primary component is in front, it is concluded that it is the primary star which is variable. In order to determine the nature of variation, the $(O-C)$ values, in magnitudes, were plotted against phase as shown in Figure 3. In doing so, since the variable star is eclipsed at the

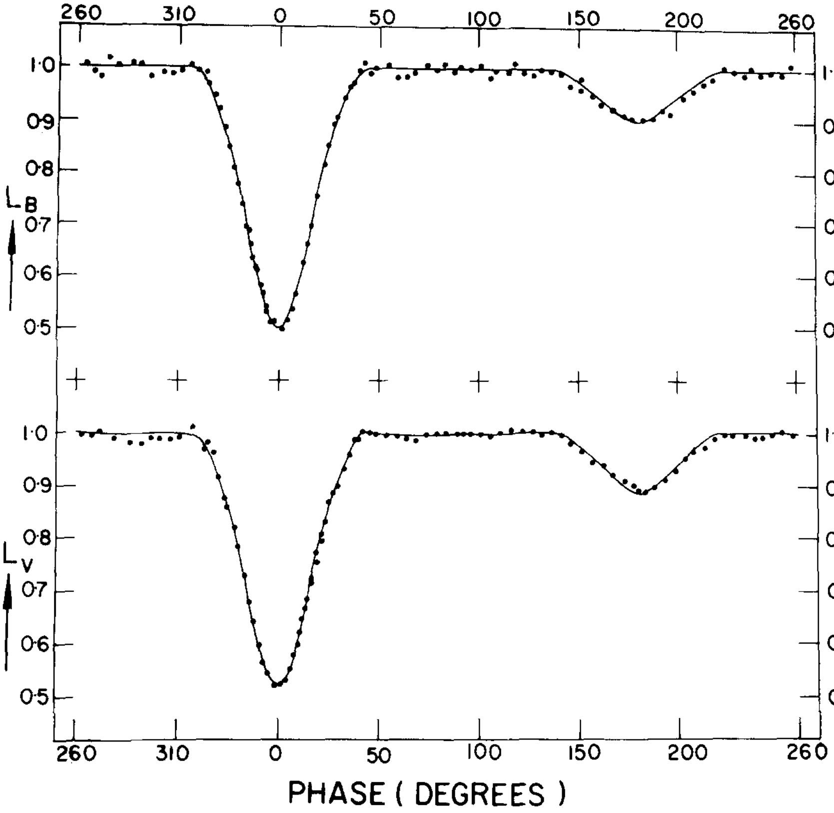

Fig. 2. Rectified light curves of WX Eridani in *B* and *V* colours. Dots represent normal points and the solid lines are computed light curves.

primary minimum, we corrected the observed $(O–C)$s in light intensity and brought them to the same units of intensity by dividing by the computed L at that phase.

An inspection of Figure 3 shows that there are five cycles in one orbital period of the binary, which indicates that the variable star is pulsating with its pulsation locked to the orbital motion with a period equal to one-fifth of the orbital period. We also see that the amplitude of variation is maximum at phase 0° and minimum at 180°. This indicates that there is a beat phenomena produced by the rotation of the primary which is presumably in synchronism with the orbital period. Thus we get two oscillations of periods equal to one-fifth and one-sixth of the orbital period. Hence we fitted the $(O–C)$s with an equation of the form:

$$(O–C) = a_1 \cos \theta + a_5 \cos 5\theta + a_6 \cos 6\theta . \tag{6}$$

A least-squares solution of the observations gave a_1, a_5 and a_6 given in Table VI. It can be seen that the fit of the theoretical expression with observations shown in Figure 3 is satisfactory. Taking into account the fact that the primary star is of

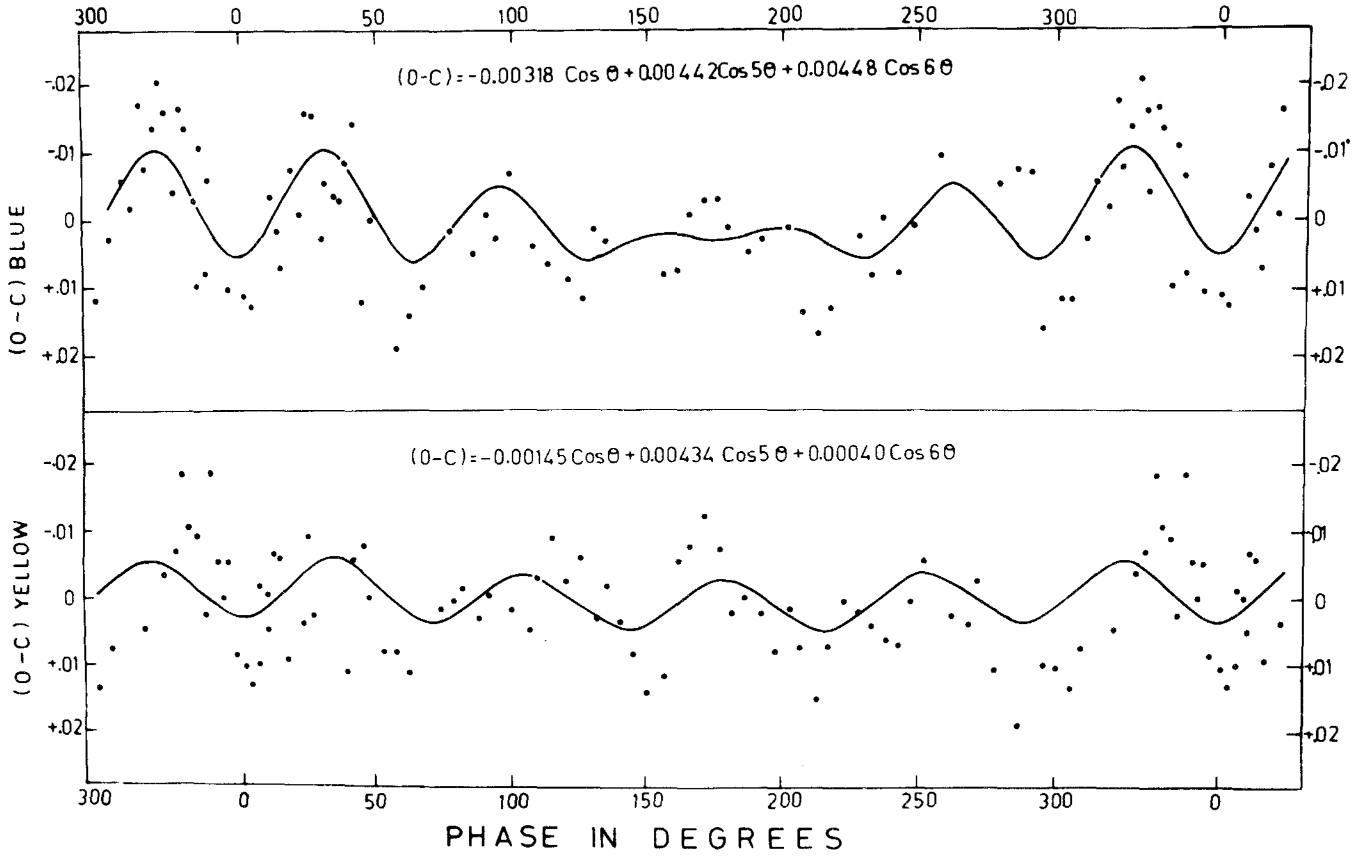

Fig. 3. Corrected $(O-C)$s for WX Eridani in B and V colours.

TABLE VI

Amplitudes of variation

Colour	a_1	a_5	a_6
V	-0.00145	$+0.00434$	$+0.00040$
B	-0.00318	$+0.00442$	$+0.00448$

spectral type F3, we can conclude that it is a δ-Scuti variable with at least two periods of $P_1 = 0\overset{d}{.}16454$ and $P_2 = 0\overset{d}{.}13721$.

6. Conclusion

Our study shows that WX Eridani can be classified tentatively as a detached eclipsing system with the primary being an F3 star pulsating like a δ-Scuti variable. Consequently, this binary may be grouped along with the binaries AB Cas, Y Cam, UX Mon and RS Cha in which one of the components is a δ-Scuti variable. Confirmation of our results by more photometric and spectroscopic observations is desirable.

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