PHOTOELECTRIC ELEMENTS OF THE ECLIPSING BINARY XY CETI

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(Received 10 March, 1975)

Abstract. The absolute elements of the system XY Ceti have been obtained on the basis of the spectroscopic elements given by Popper (1971) and the photoelectric elements derived by us. The colours of the components have been obtained. Both components are found to lie fairly on the Main Sequence. The primary component of the system, however, is slightly more evolved as it shows a tendency to drift away from the Main Sequence. The spectral classes now assigned are A5V (primary) and A7V (secondary). The values of Roche constants indicate that the system is a detached one.

1. Introduction

The algol variable XY Ceti (=BD+2°460=HD 18597=BV347=SAO 110887) was discovered and its photographic light curve was obtained by Strohmeier (1961, 1963), who determined an ephemeris given by

$$\text{Primary Minimum} = \text{JD } 2426734.285 + 1^{\text{d}}.390356 \text{ E}.$$

Later, Morrison and Morrison (1968) photoelectrically determined the epoch and period to be

$$\text{Primary Minimum} = \text{JD } 2438372.949 + 2^{\text{d}}.780712,$$

the period determined by them being exactly double the period given by Strohmeier. The spectroscopic elements of the star have been determined by Popper (1971), who also suggested that both the stars are metallic line stars and belong to the Main Sequence, the primary component being slightly more evolved.

Morrison and Morrison observed the system essentially in V filter only. Even there, no continuous set of observations spanning even one complete eclipse was obtained nor was the light curve adequately covered. For these reasons it was considered necessary to put the star on our observing programme.

2. The Observations

The star was put on our programme and was observed photoelectrically on the 38-cm reflector of the Uttar Pradesh State Observatory. A total of 22 nights of observations were secured during the period November 1969–February 1971. The light of the star was fed to an unrefrigerated 1P21 photomultiplier and the photocurrent recorded using standard DC techniques. The conventional U, B and V filters of the Johnson and Morgan system (1953) were used. The data were reduced to the standard system

Astrophysics and Space Science **38** (1975) 79–85. *All Rights Reserved*

from the observations of fourteen standard stars of various spectral types, chosen from the Arizona – Tonantzintla Catalogue of bright stars. The particulars of the variable and the comparison star along with the standard deviations of the observations are given in Table I.

TABLE I

Data on the variable and the comparison stars

Star	α_{1950}	δ_{1950}	M_v	Average standard deviation of the individual observation in U, B and V filters
XY Ceti = BD + 2° 460 = BV 357 = HD 018597 = SAO 110887	$02^h56^m56\overset{s}{.}971$	$+03°19'09\overset{''}{.}34$	$8\overset{m}{.}6$	–
Comparison star = BD + 2° 465 = SAO 110916 (Sp: A0 V)	$02^h59^m14.993$	$+02°56'29\overset{''}{.}74$	$8\overset{m}{.}4$	$\pm 0\overset{m}{.}012$ (U) $\pm 0\overset{m}{.}012$ (B) $\pm 0\overset{m}{.}012$ (V)

During the course of our observations, the whole light curve has been fairly covered except two small portions of maximum brightness. A total of 335 observations in U, 342 in B and 343 in V have been obtained and discussed.

3. Epoch and Period

During the course of our observations three primary minima and four secondary minima listed below, have been observed. These times of minima have been determined by graphical method with an accuracy of $0\overset{d}{.}001$.

Observed minima of XY Ceti

Primary minima, JD(Hel)	Secondary Minima, JD(Hel)
(1) 2 440 906.177	(1) 2 440 529.387
(2) 2 440 917.301	(2) 2 440 532.161
(3) 2 440 931.204	(3) 2 440 543.298
	(4) 2 440 557.194

Using the epoch, JD 2438372.949, given by Morrison and Morrison (1968), the period on the basis of our observations comes out to be $2\overset{d}{.}7807118$, which is essentially the same as given by Morrison and Morrison (1968).

4. Determination of Elements

The primary minimum has depths of $0^m.730$, $0^m.770$ and $0^m.695$ in *U*, *B* and *V* filters respectively, while the secondary minimum has depths of $0^m.520$, $0^m.500$ and $0^m.500$ in these respective filters.

Morrison and Morrison (1968) derived the elements of the system assuming the primary eclipse to be a partial transit and the secondary eclipse to be a partial occultation. They have also pointed out that the eclipses are nearly total.

In order to decide definitely on the nature of the eclipses we have derived the χ-values for both the eclipses. The χ-values for the secondary eclipse were 0.354, 0.359 and 0.346 in *U*, *B* and *V* filters, while those for the primary minimum were respectively 0.276, 0.283 and 0.283 showing that $\chi^{sec} > \chi^{pr}$. Normally, the eclipse that has the larger values of χ is an occultation; hence, the secondary eclipse should be an occultation and the primary eclipse a transit. The nomographic solution for an assumed value of 0.6 for limb-darkening indicates that the secondary eclipse is total, and not partial as assumed by Morrison and Morrison.

The elements have been derived with the help of Merrill's tables (1950) of ψ-functions, the procedure described by Russell and Merrill (1952) having been followed. The solution is derived on the basis of darkened discs and the value of limb-darkening coefficient is chosen as $x = 0.6$ for both the eclipses. A solution was also tried assuming $x = 0.4$, but it has been found that the fit of computed points assuming $x = 0.6$ is better than that for the other case.

The light outside eclipse (constant phase) is fairly constant. Hence, rectification of the curve was not done.

The value of $k = 0.75$ was arrived at after trials for computation of elements because the theoretical light curves computed on that basis agree well with the observations. The value of $k = 0.75$ is given by assuming (in terms of intensity outside the eclipse as unity) $\lambda_p = 0.525$, 0.520 and 0.530 for the *U*, *B* and *V* light curves. The corresponding values for the secondary minimum are $\lambda_s = 0.625$, 0.625 and 0.625.

TABLE II

Light elements of XY Ceti

$x = 0.6$ (assumed)
$P = 2^d.780\,711\,8$
Duration of totality during secondary minimum $= 0^d.02$
$k = 0.75 \pm 0.01$
$p = -1.0$
$\alpha_0^{\infty} = 1.0$
$\alpha_c^{tr} = 1.0358$
$(B-V)_1 = +0^m.163 \pm 0^m.02$
$(B-V)_2 = +0^m.177 \pm 0^m.02$
$(U-B)_1 = +0^m.099 \pm 0^m.02$
$(U-B)_2 = +0^m.113 \pm 0^m.02$
T_1 (assumed) $= 8700$ K
T_2 (assumed) $= 8100$ K

TABLE III

Geometrical elements of XY Ceti

Element	U filter	B filter	V filter	Mean of the U, B and V filters
$1-\lambda_1$	0.475	0.480	0.470	
$1-\lambda_2$	0.375	0.375	0.375	
r_1	0.173	0.171	0.170	0.171 ± 0.001
r_2	0.130	0.128	0.128	0.129 ± 0.002
J_1/J_2	1.266	1.280	1.253	1.266
i	87°.5	87°.5	87°.6	87°.5
L_1	0.625	0.625	0.625	
L_2	0.375	0.375	0.375	
θ_e	17°.5	17°.3	17°.1	17°.3
θ_i	1°.3	1°.4	1°.2	1°.3

TABLE IV

Absolute dimensions of XY Ceti

Element	U filter	B filter	V filter	Mean of the U, B and V filters
m_1 (⊙)	1.76	1.76	1.75	1.76 ± 0.02
m_2 (⊙)	1.63	1.63	1.63	1.63 ± 0.02
A ($R_\odot$)	12.51	12.51	12.51	12.51
R_1 (⊙)	2.16	2.14	2.13	2.14 ± 0.03
R_2 (⊙)	1.63	1.60	1.60	1.61 ± 0.02
ϱ_1 (⊙)	0.17	0.18	0.18	0.18 ± 0.01
ϱ_2 (⊙)	0.38	0.40	0.40	0.39 ± 0.04
M_1 (bol)	$+1^m.237$	$+1^m.258$	$+1^m.268$	$+1^m.254 \pm 0^m.157$
M_2 (bol)	$+2^m.160$	$+2^m.200$	$+2^m.200$	$+2^m.187 \pm 0^m.015$
M_1 (vis)	$+1^m.638$	$+1^m.659$	$+1^m.669$	$+1^m.655$
M_2 (vis)	$+2^m.501$	$+2^m.541$	$+2^m.541$	$+2^m.528$
$\log(L_1/L_\odot)$	1.357	1.349	1.345	1.350
$\log(L_2/L_\odot)$	0.988	0.972	0.972	0.977

Next, using the spectroscopic elements given by Popper (1971), the absolute dimensions of the system have been obtained. All the elements of the system are given in Tables II, III and IV in which subscripts 1 and 2 refer to the primary and the secondary components respectively.

The computed points are determined from the well known relation:

$$\sin^2 \theta = A + B\psi,$$

where θ is the phase and A, B are constants derived from the individual light curves for both the eclipses in U, B and V filters.

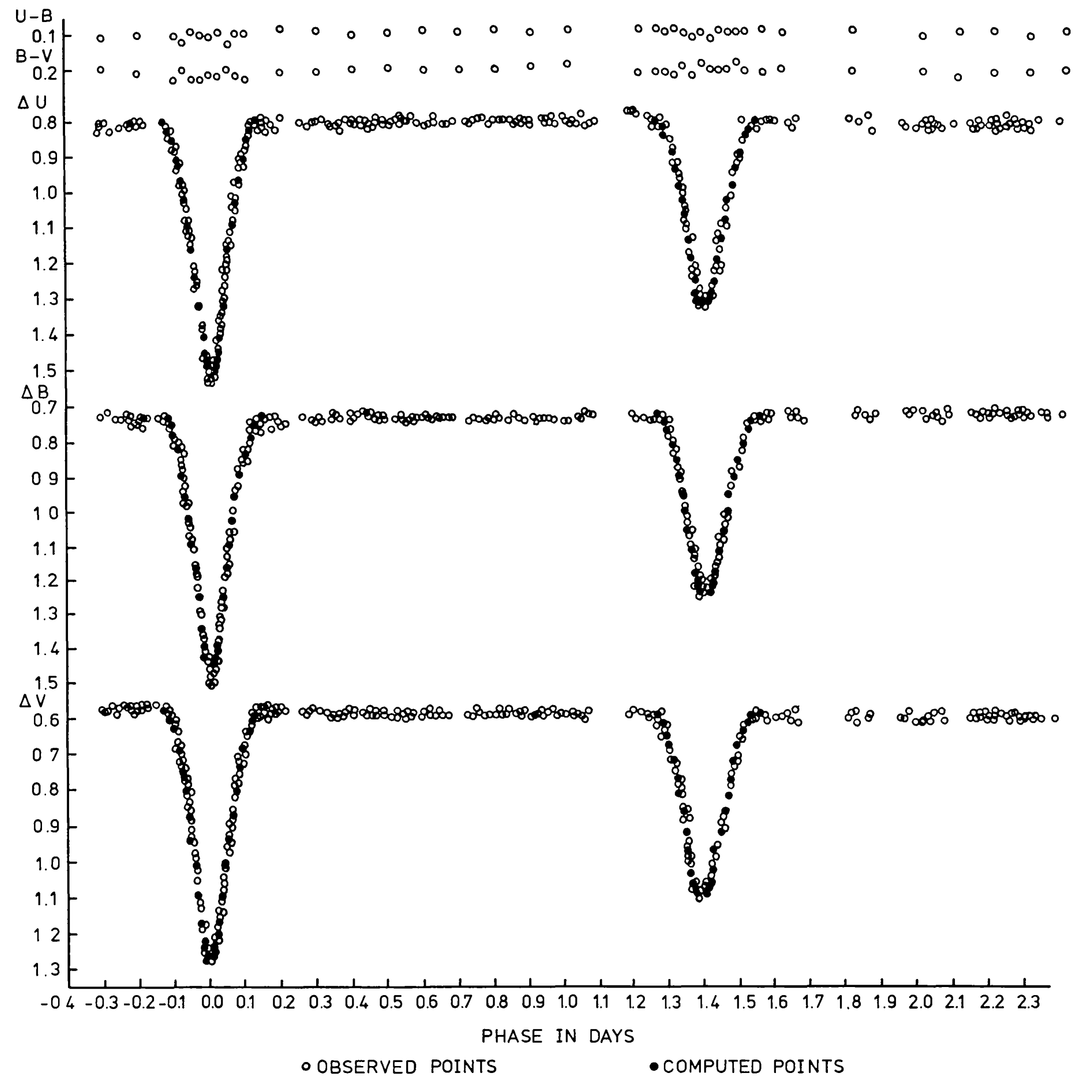

Fig. 1. Light curves of XY Ceti.

5. Colour and Luminosity Classification

The colours of the comparison star were obtained on various nights, the average colours being $B-V=+0\overset{m}{.}048$ and $U-B=+0\overset{m}{.}029$. These values indicate that the comparison star belongs to spectral class A1V (Arp, 1958). The standard magnitudes ΔU, ΔB and ΔV have been read out from the individual light curves, given in Figure 1, at maximum (constant phase) and at secondary minimum (occultation eclipse). Then $\Delta(B-V)$ and $\Delta(U-B)$ values have been obtained. At maximum the combined light of the components is read out, while at the time of secondary minimum only the light of primary component is observed. Based on these considerations the $\Delta(B-V)$ and $\Delta(U-B)$ values for the secondary component have been obtained by usual methods. To these $\Delta(B-V)$ and $\Delta(U-B)$ values for both the components, the colours of the comparison star have been added to get the $(B-V)$ and $(U-B)$ values for both the components. The colour curves are given in Figure 1.

The colour of the primary (brighter and, in this case, also larger) component comes out to be $B-V=+0\overset{m}{.}193$ and $U-B=+0\overset{m}{.}099$. The colour of the secondary component is found to be $B-V=+0\overset{m}{.}207$ and $U-B=+0\overset{m}{.}113$. The maximum error of observations in U, B and V filters is of the order of $0\overset{m}{.}02$.

According to Popper (1971) the metallic line characteristics in both components of XY Ceti are well marked. Hence, after applying a metallicity correction of $0\overset{m}{.}03$ (Johnson *et al.*, 1966) to the observed $B-V$ values of primary and secondary components, the corrected values of colour for the two components are:

Primary: $B-V=+0\overset{m}{.}163$ $U-B=+0\overset{m}{.}099$

Secondary: $B-V=+0\overset{m}{.}177$ $U-B=+0\overset{m}{.}113$

On plotting these values of $B-V$ and $U-B$ of the two components on the $(B-V)$ vs $(U-B)$ diagram for unreddened stars taken from Johnson and Morgan (1953), we find that both the components lie fairly on the Main Sequence and belong to A5V and A7V classes respectively, implying that there is no appreciable colour excess.

On plotting the quantities concerned on $\log m/\log R$ plot (Kopal, 1955), we find that the secondary component lies fairly on the Main Sequence while the primary (bigger) component seems to lie above it.

Based on the above classification of the primary (A5V) and the secondary (A7V) components the bolometric magnitudes have been computed using the relation given by Kopal (1959). The values of bolometric magnitudes come out to be $+1\overset{m}{.}254$ and $+2\overset{m}{.}187$ for the primary and secondary components respectively, for assumed values of 8700 K and 8100 K (see Arp, 1958) for the effective temperatures of the primary and the secondary components respectively. When these bolometric magnitudes are plotted against spectral type, following the data for the Main Sequence stars (Arp, 1958), it is found that the secondary component lies on the Main Sequence while the primary component is slightly more evolved showing a tendency to get away from the Main Sequence, which is a further confirmation of the previous finding.

The values of absolute visual magnitudes have been determined from the relation:

$$M(\text{vis}) = -5\log R + \frac{29\,500}{T_e} - 0.08,$$

for the above assumed effective temperatures of primary and the secondary components. These magnitudes come out to be

$$M_v\,(\text{primary}) = +1\overset{m}{.}655; \qquad M_v\,(\text{secondary}) = +2\overset{m}{.}528.$$

The values of Roche constants C_1 and C_2 have been calculated following the relation given by Kopal (1955) and come out to be $C_1=7.3$ and $C_2=8.8$. The value of Roche constant $C_0=3.9990$ has been read out from the table (Kopal, 1959, p. 136) corresponding to the mass ratio $m_2/m_1=0.93$. Since $C_1>C_0$ and $C_2>C_0$, we infer that the system is a detached one.

Acknowledgement

This work was carried out under the guidance of Dr S. D. Sinvhal. The authors are thankful to him for helpful suggestions.

References

Arp, H. C.: 1958, in *Handbuch der Physik* **51**, 83.
Johnson, H. L. and Morgan, W. W.: 1953, *Astrophys. J.* **117**, 313.
Johnson, H. L., Mitchell, R. I., Iriarte, B., and Wisniewski, W. Z.: 1966, *Lunar Planet. Lab. Commun.* **4**, 99.
Kopal, Z.: 1955, *Ann. Astrophys.* **18**, 405.
Kopal, Z.: 1959, *Close Binary Systems*, Chapman and Hall, London, p. 495.
Merrill, J. E.: 1950, *Princeton Contr.* No. 23.
Morrison, D. and Morrison, N. D.: 1968, *Astron. J.* **73**, 777.
Popper, D. M.: 1971, *Astrophys. J.* **169**, 549.
Russell, H. N. and Merrill, J. E.: 1952, *Princeton Contr.* No. 26.
Strohmeier, W.: 1963, *Sky Telesc.* **26**, 264.
Strohmeier, W.: 1961, *Astron. Nachr.* **286**, 133.