Bull. Astr. Soc. India (1982) 10, 323–328

Photometric solution for the eclipsing binary TT Aurigae

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Received 1982 July 15; accepted 1982 October 15

Abstract. Photometric elements of TT Aur are derived from the *UBV* observations of the star during 1973–77. The system is found to be detached but quite close. Absolute dimensions are obtained on the basis of the spectroscopic element given by Joy & Sitterly (1931). It appears that the radial velocity amplitudes found by them might need upward revision by about 50 km s^{-1}.

Key words: TT Aur—eclipsing binary—photometry

1. Introduction

TT Aurigae is a Beta Lyrae type detached eclipsing binary containing two early-B type stars. Its importance lies in its being a spectroscopic binary as well, which enables us to determine its absolute dimensions. After the discovery by Miss Leavitt (1907) the star has been observed photometrically by Enebo (1908, 1909), Münche (1909), Balanowsky (1913), Martin & Plummer (1916), Jordan (1929) and Joy & Sitterly (1931). Photometric orbital elements were calculated by Balanowsky (1913) and Joy & Sitterly (1931). The only spectroscopic study is that due to Joy & Sitterly (1931) who determined the spectroscopic orbit and absolute dimensions of the system.

As no photoelectric observations of TT Aur were available it was put on the observing program of Japal-Rangapur observatory. The star was observed by Kulkarni & Lokanadham (1978) during 1973–77 in *UBV* colours with the photoelectric photometer attached to the 48-inch telescope. Their observations have already been published as Nizamiah and Japal-Rangapur observatory contribution No. 8 in which they give an improved period of 1.3327333 d. We have used their data for deriving new photometric eclipse elements by the Russell-Merrill method.

2. Rectification of light curve

On plotting the light curves according to the phases computed from the light elements given by Kulkarni & Lokanadham (1978) it was found that there was a

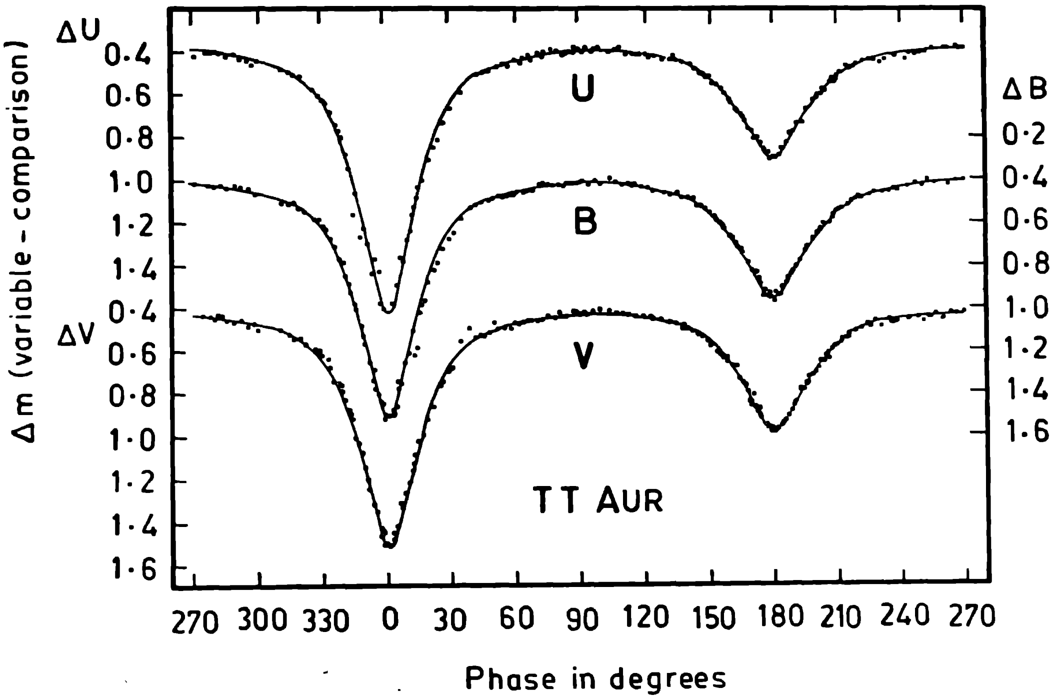

Figure 1. The observed light curves of TT Aur. The dots are the normal points and the theoretical curve is represented by the continuous line.

phase shift of 0°.87 in both minima. The normal points obtained after applying this correction as tabulated by Rajasekhar Rao (1981) are plotted in figure 1 which clearly shows the Beta Lyrae character of the light curves in all the three colours.

The magnitudes were converted into luminosities by subtracting the mean magnitude at maximum which was found to be 0.431, 0.411, and 0.389 in *V*, *B* and *U*, respectively. The graphical method of Russell & Merrill (1952) was used for a preliminary determination of θ_e, the angle of external tangency. The method of least squares was then used for representing all the observed points outside the eclipse range by a Fourier series. Terms including both cosine and sine terms up to 3θ were found to be adequate, the coefficients of 4θ terms being small compared to their probable errors. The Fourier coefficients so obtained are given in table 1.

Table 1. Computed Fourier coefficients for TT Aur

Coefficients	*V*	*B*	*U*
A_0	+0.9369 ±0.0010	+0.9297 ±0.0011	+0.9247 ±0.0012
A_1	−0.0279 ±0.0030	−0.0157 ±0.0032	−0.0386 ±0.0035
A_2	−0.0666 ±0.0014	−0.0691 ±0.0016	−0.0702 ±0.0017
A_3	−0.0024 ±0.0019	+0.0034 ±0.0020	−0.0058 ±0.0022
B_1	+0.0028 ±0.0007	+0.0013 ±0.0008	+0.0004 ±0.0008
B_2	−0.0011 ±0.0008	+0.0012 ±0.0008	−0.0008 ±0.0009
B_3	+0.0012 ±0.0009	+0.0013 ±0.0010	+0.0022 +0.0011

For the next step of obtaining the rectification constants we used Cester's (1969) luminous efficiency tables taking the spectral types of primary and secondary as B2 and B4, respectively, which are close to their final spectral types. The rectification constants are given in table 2. Rectification of light was performed as per precepts of Russell & Merrill (1952) by : (i) subtracting the sine terms, (ii) adding the reflection terms, and (iii) finally dividing the resultant light by the sum of the constant term and all the cosine terms. Rectification for phase was performed by taking $Z = 0.16$ corresponding to $X = 0.4$ and $N = 2.2$. The rectified light curves are shown in figure 2.

Table 2. Rectification parameters for TT Aurigae

Quantity	*V*	*B*	*U*
$^*\lambda_{eff}$ (A)	5470	4330	3550
E_c/E_h	1.500	1.493	1.172
J_h/J_c	2.125	2.125	2.125
G_c/G_h	3.392	3.359	2. 069
X (primary)	0.33	0.4	0.3
X (adopted)	0.4	0.4	0.4
X (secondary)	0.35	0.4	0.3
X (adopted)	0.4	0.4	0.4
N	2.2	2.2	2.2
Z	0.1475	0.1408	0.1891
Z (adopted)	0.16	0.16	0.16
C_0	0.0375	0.0213	0.0813
C_2	0.0128	0.0072	0.0277

*For both primary (B2) and secondary (B4)

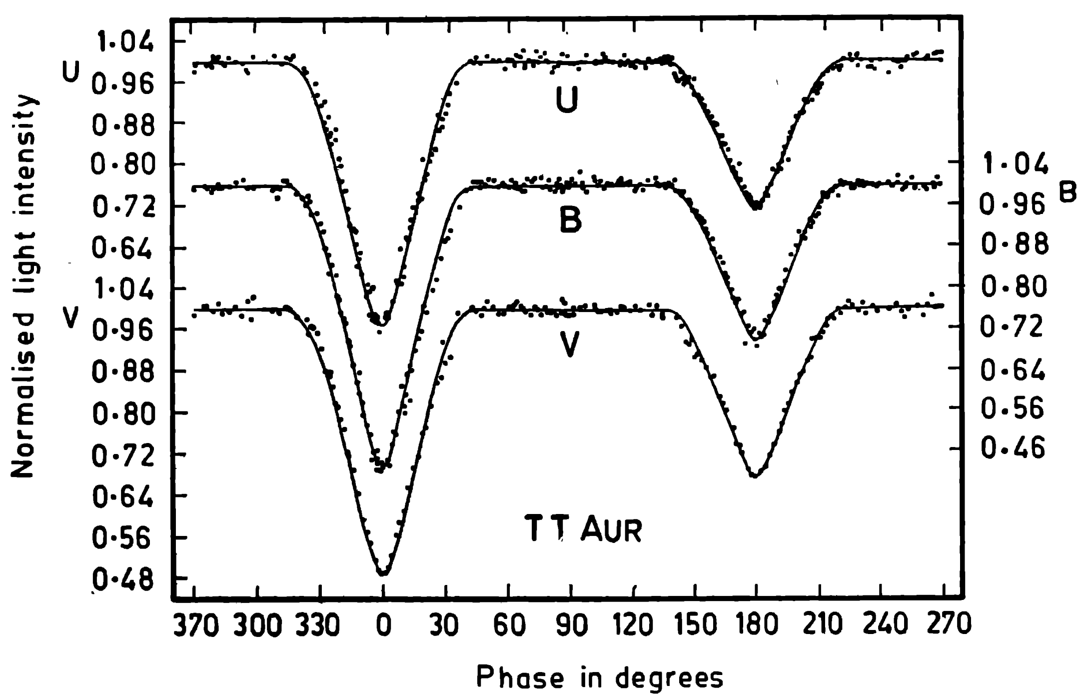

Figure 2. Rectified light curves of TT Aur. Dots are normal points and continuous line is theoretical curve.

3. Photometric elements

The solutions of the light curves were obtained by (i) obtaining an estimate of the range of k values by plotting the shape and depth curves; (ii) determination of the angle of external tangency by Wellmann's (1953) method for various values of k by reading off the required values of α_0^{oc} or α_0^{tr} from the depth curve; (iii) computation of $\Sigma w_i (O - C)_i^2$, where $W_i = N_i/l_i^2$, the weighted sum of the residual squares from the elements derived for each value of k; and (iv) determination of the best value of k and other elements by plotting the weighted sums of the squared residuals as a functions of k and noting the minimum.

Figure 3 shows the weighted sums of squared residuals in the three colours for the primary and secondary eclipses separately as well as for the total of both. The minima are shown by arrows; on giving equal weignts to all the nine values of k so obtained we find that the primary eclipse is a transit with $k = 0.92 \pm 0.05$. The elements corresponding to this value of k are shown in table 3. The fit of the observed normal points is shown by the continuous line in figure 2 for rectified light and in figure 1 for observed magnitudes. The representation is quite satisfactory for all the three colours.

4. Absolute dimensions

The only spectroscopic orbit of TT Aur is that due to Joy & Sitterly (1931) published 50 years ago. It was based on 32 spectrograms obtained between 1917 and 1930.

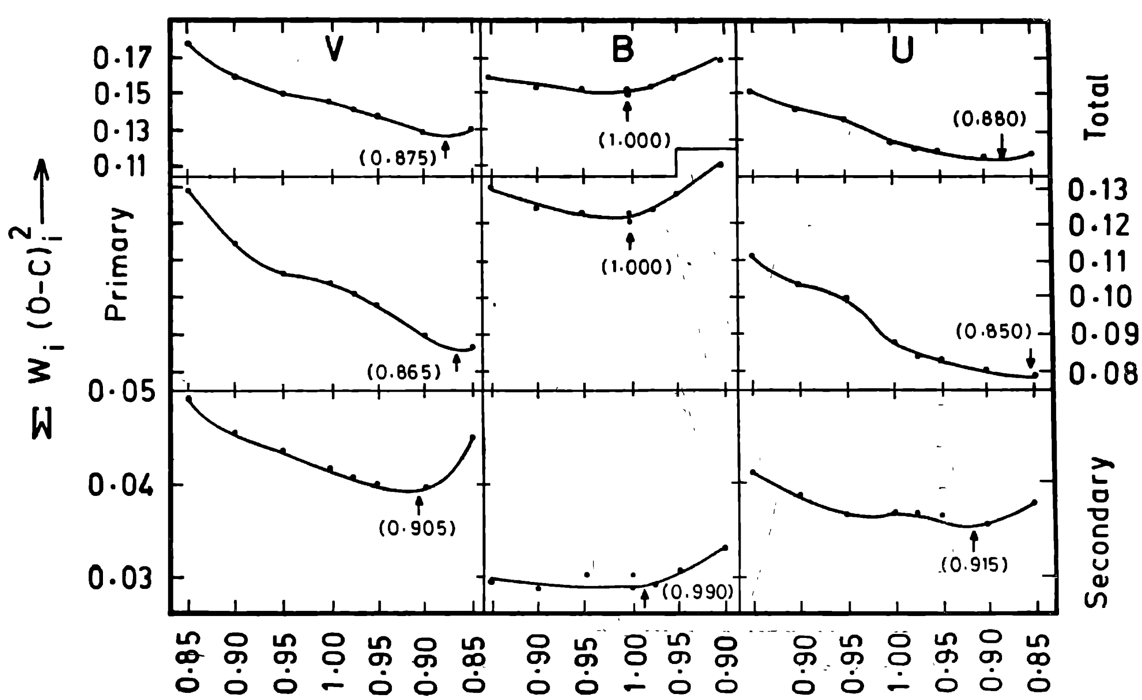

Figure 3. The weighted sums of the residual squares plotted as a function of k for both possibilities: primary as occultation (on left) and primary as transit (on right). Minima are indicated by arrows.

Table 3. Photometric elements of TT Aurigae ($K = 0.9 \pm 0.05$, primary transit)

Element	V	B	U	Mean
r_g	0.353 ± 0.010	0.349 ± 0.010	0.346 ± 0.010	0.349 ± 0.010
r_s	0.325 ± 0.010	0.321 ± 0.010	0.318 ± 0.010	0.321 ± 0.010
i	84°.9 ± 0°.6	85°.4 ± 0° 4	83°.9 ± 0°.5	84°.7 ± 0°.5
θ_e	42.4 ± 0.2	41.9 ± 0.2	41.2 ± 0.2	41.8 ± 0.2
α_0^{tr}	0.900 ± 0.058	0.917 ± 0.058	0.867 ± 0.058	0.895 ± 0.058
α_0^{oc}	0.915 ± 0.058	0.925 ± 0.058	0.880 ± 0.058	0.907 ± 0.058
l_g	0.650 ± 0.021	0.677 ± 0.021	0.679 ± 0.022	
l_s	0.350 ± 0.021	0.323 ± 0.021	0.321 ± 0.022	
L_g	0.699 ± 0.023	0.732 ± 0.023	0.717 ± 0.023	
L_s	0.301 ± 0.023	0.268 ± 0.023	0.283 ± 0.023	
J_g/J_s	1.97 ± 0.22	2.31 ± 0.25	2.15 ± 0.24	
m_g	8.990 ± 0.036	9.025 ± 0.034	8.380 ± 0.035	
m_s	9.905 ± 0.080	10.817 ± 0.084	9.391 ± 0.085	

Using their data and our values of radii and inclination we have calculated the dimensions of the system. They are given in table 4 which also gives the magnitudes and colours of the two components obtained from our photometric results after correcting for reflection effect. Here we have used the outside eclipse values of $V = 8.539$, $B - V + 0.086$ and $U - B = -0.658$ for TT Aur obtained from the data for the comparison star HD 32989 given by Kulkarni & Lokanadham (1978). The corresponding spectral types as inferred from the data given in Allen's (1973) tables are also indicated.

Table 4. Absolute Dimensions of TT Aur ($m_2/m_1 = 0.79$)

Parameter	Primary	Secondary
$a/R_\odot$	5.20	6.50
$R/R_\odot$	4.09 (B4)	3.76 (B5)
$m/m_\odot$	6.79 (B5)	5.37 (B6)
R/R^*	0.88 ± 0.02	0.91 ± 0.02
V	8.990 ± 0.035	9.905 ± 0.080
$B - V$	0.035 ± 0.005	0.212 ± 0.005
$U - B$	−0.645 ± 0.035	−0.726 ± 0.085
Q	−0.67 ± 0.04 (B2)	−0.88 ± 0.09 (B0)?

First we note that the radii of the two components are about 90 per cent of their respective Roche lobes; the system is therefore, definitely detached but quite close. In the case of the primary we obtain a spectral type of B2 from the Q value calculated with its observed $B - V$ and $U - B$ colours. Further, assuming an extinction of 0.27 mag kpc^{-1} in $B - V$ we get a distance of one kiloparsec for the system. But the mass and radius of the primary obtained by combining the photometric and spectroscopic data suggest a spectral type of B4–5. The discrepancy of two subclasses in spectral type would be removed if the radial velocity amplitudes for the two components were 250 km s^{-1} and 300 km s^{-1}, respectively, instead of 197 km s^{-1} and 240 km s^{-1} found by Joy & Sitterly (1931). Such a revision might possibly be revealed by new and better spectroscopic observations. Joy & Sitterly have pointed out the inherent inaccuracy of their measurements caused by the large rotational broadening of the spectral lines of the order of 340 km s^{-1}.

The Q value for the secondary corresponds to spectral type B0 which indicates that it has an ultraviolet excess. Taking $B - V$ excess of $+0.28$ corresponding to that for primary we get $B - V = -0.07$ which gives a spectral type B8 for the secondary. In that case it will have an UV excess of -0.70 mag. However, the surmised upgrading of the radial velocity amplitude would make the secondary a B3 star instead of B5 — 6 as indicated by the presently determined mass and radius. In that case its observed $B - V$ and $U - B$ colours would make it about 0.25 mag underluminous in B and about 0.15 mag overluminous in U. Accurate spectroscopic observations of this system are urgently required.

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