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A Model of the Algol Type Close Binary TT Hydrae

A. G. Kulkarni* and K. D. Abhyankar *centre of Advanced study in Astronomy, Osmania University, Hyderabad 500007*

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Abstract. *UBV* photometric observations and elements of TT Hydrae obtained by Kulkarni and Abhyankar (1980) are combined with the radial velocity curve of Popper (1979, personal communication) to derive the absolute dimensions and. a model of this important Algol system. While the photometric ratios of radii in *V* and *B* are in agreement giving $k = 0{\cdot}3812$ for a limb darkening coefficient of $x = 0{\cdot}6$, application of Irwin's (1947) method gives $x = 0{\cdot}4$ for *U*. The primary is found to be a main sequence Al V star of mass 2·61 $M_{\odot}$ and radius 2·01 $R_{\odot}$, and the secondary is classified as a Kl III star of mass 0·70 $M_{\odot}$ and radius 5·33 $R_{\odot}$. The observed Fourier coefficients for the light outside the eclipse agree with those calculated from theory for the reflection and ellipticity effects. The system shows an ultraviolet excess of 0·5 to 0·6 magnitudes during primary eclipse, which is attributed to an asymmetric circumstellar distribution of matter around the primary. The evolutionary status of the secondary, which does not appear to fill its Roche lobe completely, is discussed.

Key words: close binaries—absolute dimensions—ultraviolet excess in Algols

1. Introduction

TT Hydrae (variously designated as HD 97528, CD –25° 8531, CPD –25° 4711, Gou 15354, Cord A 8686) was discovered to be an eclipsing variable of Algol type by Wood (1926) at the Union Observatory in Johannesburg. Since then it has been studied photometrically by Hertzsprung (1928), Reilly (1946) and Shapley (1927) who made the first attempt to derive the photometric orbit using Hertzsprung's observations.

*Present address: Sardar Patel Planetarium, Sayaji Baug, Baroda 390018

Systematic spectroscopic investigations were initiated by Wyse (1934) who reported that the spectrum of the secondary star of the system contains bright hydrogen lines. The first spectrographic orbit is due to Sanford (1937) who obtained 16 spectrograms spread over a period of 6 years from 1930 to 1936, all outside the primary minimum. The orbit was found to be fairly circular (e = 0·08). Sahade and Cesco (1946) also gave spectrographic orbits based on Ca II K line as well as hydrogen lines. These orbits are somewhat eccentric with e = 0·12 for the Ca II line and e = 0·24 for hydrogen lines. The third spectroscopic study is due to Miller and McNamara (1963). They obtained six spectra of the primary and one spectrum of the secondary. Their velocities from the spectra of the primary agree well with Sahade and Cesco's orbit from Ca II K line. They have obtained the mass ratio of 0·17 and hence the masses of the component stars as 13 2 $M_\odot$ and 2·3 $M_\odot$ for the primary and the secondary, respectively.

From the evolutionary point of view, the system of TT Hydrae is somewhat controversial. Kopal (1959) lists this system as one with an ' undersize subgiant secondary' under the assumption that the present secondary is less massive now after the loss of matter to the present primary in its evolutionary history. Later, Hall (1974) examined this list of systems with 'undersize subgiant secondaries' along with a few other systems, and came to the conclusion that there is no evidence to support the notion that such a subgroup of post-main sequence mass exchange remnants exists in which the subgiant is smaller than its Roche lobe. Discussing this particular system (TT Hydrae), Hall says, "If the error in the relative radius of the cooler component were ±0·02 instead of ±0·01, the computed and observed K_h (velocity amplitudes of the hotter components) will agree". The computed K_h is obtained under the assumption that the secondary fills its Roche lobe. Thus there is a need for determining the radii of the component stars with better accuracy.

We have tried to obtain the absolute dimensions and a model for TT Hydrae by combining our photometric elements (Kulkarni and Abhyankar 1980, hereafter called Paper I) with the most recent and accurate spectrographic observations of this system by Popper (1979, personal communication). He obtains the velocity curve for the primary and the secondary using the image tube spectrograms. For primary, he uses numerous lines in the photographic region and finds that the curve is not perfectly sinusoidal. The secondary appears to be showing good sinusoidal variation. Measurements for the secondary were made using the sodium D lines.

2. Photometric study

2.1 *Observations*

This binary system was observed by us in *UBV* on 63 nights during a period of four years from 1973 to 1977, with a photoelectric photometer attached to the 1·2–m reflector telescope of the Japal-Rangapur Observatory. All the observations were reduced to the standard *UBV* system of Johnson by observing several standard stars. The individual observations are already published (Kulkarni and Abhyankar, 1978) and the light curves based on them were plotted in Figs 1 and 2 of Paper I, which show that the primary eclipse is total. The $B-V$ and $U-B$ colours for the primary

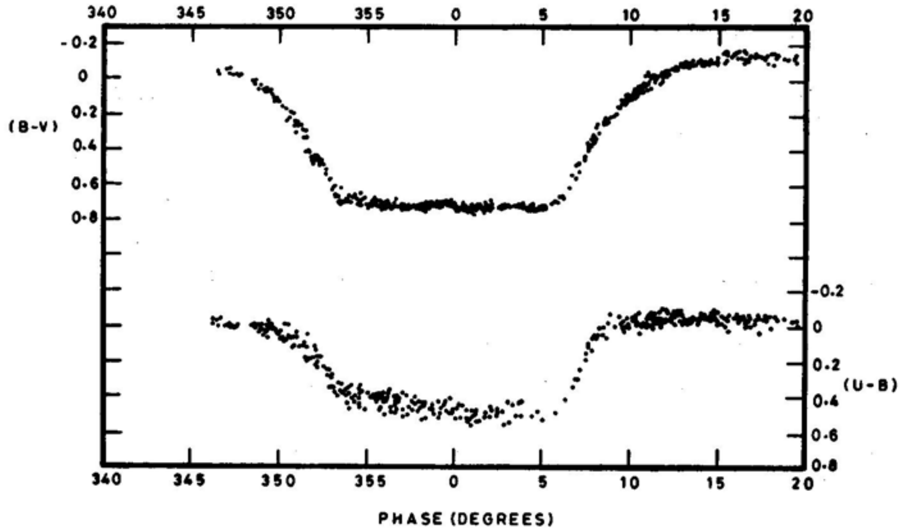

Figure 1. Primary eclipse of TT Hydare in ($B-V$) and ($U-B$) colours

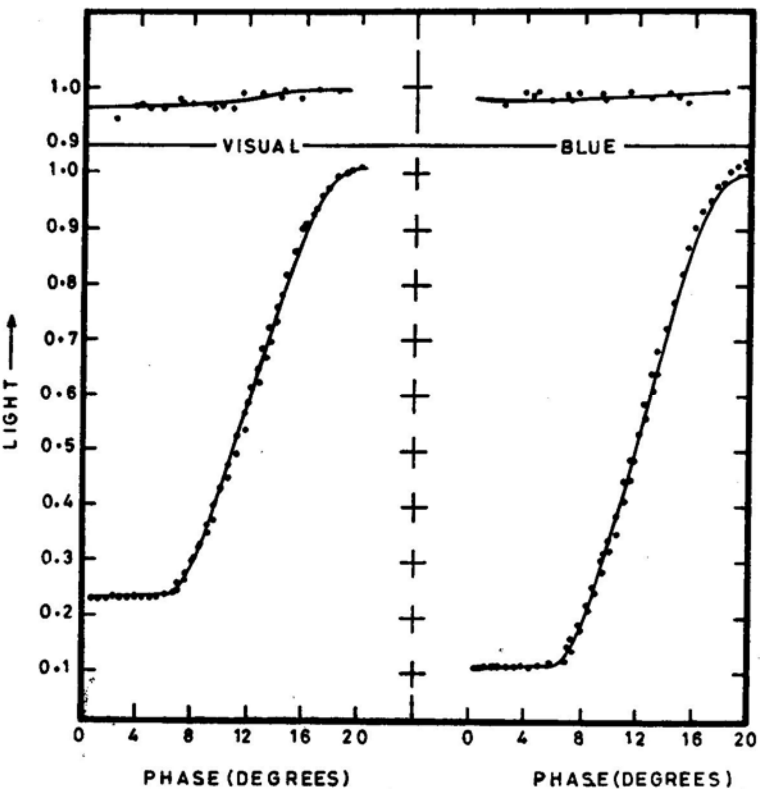

Figure 2. Fit of observed normal points (rectified) to the computed elements for primary and secondary eclipse in V and B.

eclipse phases are plotted in Fig. 1 of this paper. Eggen (1978) has published his magnitude and colour observations outside and inside the eclipse. Our values agree very closely with his values. The normal points obtained from the 931 observations in *V*, 855 observations in *B* and 761 observations in *U* as tabulated by Kulkarni (1979) are shown in Fig. 2.

2.2 *Rectification*

1. The light outside the eclipse was represented by a series of the type:

$$L = A_0 + A_1 \cos\theta + A_2 \cos 2\theta + A_3 \cos 3\theta + A_4 \cos 4\theta + \ldots . + B_1 \sin\theta + B_2 \sin 2\theta + B_3 \sin 3\theta + B_4 \sin 4\,\theta \ldots . \tag{1}$$

The constants and their probable errors are listed in Table 1.

2. The Reflection constants C_0 and C_2 were obtained from the ratio of the surface brightness given by the primary and secondary depths and the tables of luminous efficiencies given by Cester (1969). For this purpose, the primary spectrum was assumed to be of type A3 and the secondary was assumed to be of type G5. All the relevant parameters are listed for each colour in Table 2.

Table 1. Fourier coefficients of the harmonic representation.

Coefficient	*V*	*B*	*U*
A_0	·95762±·00115	·97521±·00128	·97672±·00168
A_1	−·01379±·00159	−·01103±·00176	−·01479±·00241
A_2	−·03479±·00187	−·01635±·00204	−·01012±·00267
A_3	·00111±·00159	·00153±·00177	−·00202±·00240
A_4	−·00650±·00163	−·00608±·00183	−·00703±·00247
B_1	·00556±·00105	·00701±·00118	·00947±·00162
B_2	−·00237±·00094	−·00180±·00103	−·00401±·00148
B_3	−·00296±·00114	−·00330±·00127	−·00259±·00175
B_4	−·00087±·00127	−·00022±·00144	·00352±·00195
p.e.	·00142	·01037	·01378

Table 2. Parameters for rectification.

Quantities	*V*	*B*	*U*
λ_{eff} (Å) (Primary, A3)	5480	4400	3650
λ_{eff} (Å) (Secondary, G5)	5510	4500	3800
E_c/E_h	·96859	·57358	·61517
J_h/J_c	19·41	44·32	202·00
G_c/G_h	18·2095	14·5797	76·4429
x (A3)	·520	·680	·648
x (adopted)	·6	·6	·6*
N	2·6	2·6	2·6
z	·06037	·03046	·02185
C_0	·01154	·00949	·01139
C_2	·00385	·00316	·00379

*The limb darkening coefficient x for ultraviolet is computed later to be 0·42 from. Irwin's (1947) method of obtaining differential limb darkening coefficient. However, initially x was taken as 0·6 for the *U* solution as well.

3. Rectification of light curve was performed by (i) initially removing the asymmetric sine terms (B_i sin $i\theta$, i= 1, 2, 3, 4) by subtraction, (ii) adding subsequently the reflection terms ($C_0 - A_1 \cos \theta + C_2 \cos 2\theta$), (iii) further effecting the rectification for ellipticity of the stars with division by the factor (A_0 + C_0) +(A_2 + C_2) cos 2θ + A_3 cos 3θ + A_4 cos 4θ and (iv) finally rectifying the phases in the customary manner with x and z given in Table 2.

3. Solution of the light curve

3.1 *Determination of the Ratio of Radii*

The light curves show that the primary eclipse is deep while the secondary eclipse is very shallow (0.07 mag in *V,* 0.02 mag in *B* and almost zero in *U*). Therefore, it was decided to solve only the primary eclipses and later use these elements to representthe light curve in the secondary eclipses. It is also evident from the totality phase that the primary eclipse is an occultation while the secondary eclipse is a transit. From the rectified light curves, the fractional light losses $\alpha = (1 - l)/(1 - l_0)$ were computed, where l_0 is the light in the total phase of the eclipse.

Kopal's (1959) first method was used to solve all the three (*V, B* and *U*) light curves. In this method, for each assumed value of *k,* the ratio of radii, the rectified phases Θ and the corresponding geometrical depths *p* are fitted to an equation of the type

$$y = mx + c,$$

Where

$$y = \sin^2 \Theta,\ x = (1 + kp)^2,\ m = r_g^2 \operatorname{cosec}^2 i, \text{ and } c = \cot^2 i, \tag{4}$$

by the method of least squares with the weights

$$W_i = \frac{n_i}{l_i^2 (1 + kp_i)^2 \left(\frac{dp}{d\alpha}\right)_i^2}, \tag{5}$$

where n_i is the number of observations in each normal point. It may be noted that these weights apply for the deviation in $\sin^2 \Theta$. This fit was obtained for various values of *k* with an initial value of 0·35, and steps of 0·025. The quantity $\Sigma\ W_i\ (O - C)_i^2$ was computed for each *k,* and plotted in Fig. 3(a). As is evident from the figure the best fit is obtained for *k* =0·4375, 0·4300 and 0·4575 for *V, B* and *U,* respectively. As the *k* values for *V* and *B* are close to each other while that for *U* is rather removed from both, we took the average of *V* and *B* results to obtain a value of *k* = 0·4337.

The above procedure (Kopal's first method) assumes that the observed phases (times of observation) are in error and not the observed lights. However the observed lights do have errors whereas the phases are comparatively accurately determined quantities. We proceeded to correct for this effect. For each value of *k,* the values

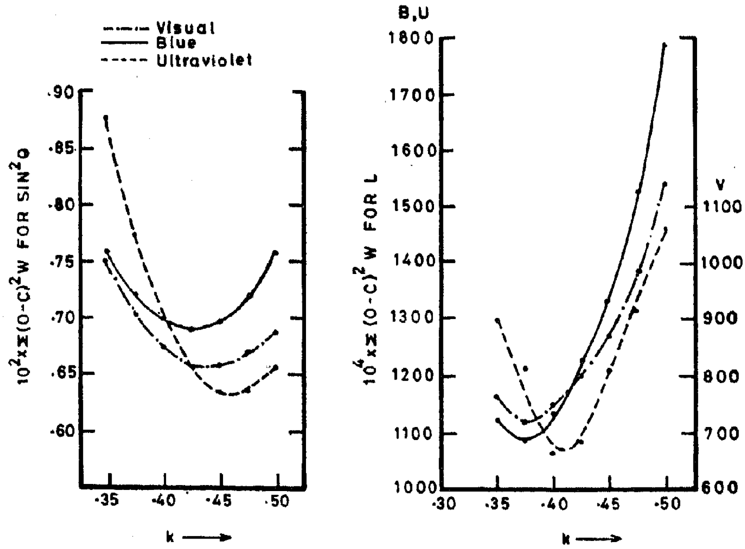

Figure 3. Sum of the weighted $(O - C)^2$ plotted against k for (a) $\sin^2\Theta$ (b) light.

of r_g, i and p (Θ) obtained from the Kopal solution were used for computing the light at the phases of each normal point. Then taking the appropriate weights for light as (n_i / l_i^2), we obtained $\sum W_i (O - C)_i^2$, for various values of k. They are shown in Fig. 3(b). We find that the best fit now occurs at k= 0·3825, 0·3800 and 0·4075 for V, B and U respectively. Again, the k value for U differs from that for V and B, so we took the mean for V and B which gave k = 0·3812. We feel this to be the correct value of k and not the earlier one where the phases were presumed to be in error.

The secondary eclipses in V and B were further represented by using the elements obtained from the primary, with k = 0·3812 and also with k = 0·4337. We find that the weighted $(O - C)^2$ are much less in the case of k = 0·3812 than in 0·4337. In the former case, $\sum W_i (O - C)_i^2$ is 68 $\times 10^{-4}$ and 85 $\times$ 10^{-4} in V and B respectively while in the latter case the corresponding values are 164 $\times$ 10^{-4} and 145 $\times$ 10^{-4}. This fact further confirms that the former (0·3812) value of k is the correct one and not the latter (0·4337).

3.2 *Elements of the Binary*

After determining the value of k, the values of i, the inclination of the orbit and r_g, the relative radius of the larger component, were obtained by interpolation from the values of these quantities derived for various values of k. They come out to be i = 83°·64, r_g = 0·2438 and therefore r_s= 0·0929 since k = r_s/r_g= 0·3812. All the photometric elements are given in Table 1 of Paper 1 which are reproduced in Table 3 for completeness.

Representation of the primary and the secondary eclipses using computed elements is shown by the continuous line in Fig. 2 for V and B.

Table 3. Photometric orbital elements of TT Hydrae.

Element	Present study	Shapley (1927)
θ_e	18°·55	
X_s (V, B)	0·6	
X_g (V, B)	0·8	
X_s (U)	0·4	
k	0·3812	0·30
j	83°·74	82°·6
r_g	0·2438	0·240
r_s	0·0929	0·072
L_s (V)	0·7682	
L_g (V)	0·2318	
J_s/J_g (V)	19·41	
L_s (B)	0·8858	0·895
L_g (B)	0·1142	0·105
J_s/J_g (B)	44·32	95
L_s (U)	0·9100	
L_g (U)	0·0900	
J_s/J_g (U)	~200	

3.3 *Limb Darkening in Ultraviolet*

We have already noted that the values of *k* for *V* and *B* are closer to each other while that for *U* is somewhat different. This could presumably be due to a wrong choice of limb darkening (x = 0·6) for *U*. Hence, we took the mean geometrical elements obtained from *V* and *B* light curves to be representative of the system and obtained the value of x_U by Irwin's (1947) method. In this way we find x=0·42 for *U*. On using this value of *x* and *k* = 0·3812 (mean for *V* and *B*) we found that the sum of weighted $(O - C)^2$ was significantly reduced (by about 40 per cent) as compared to x= 0·6. This clearly indicates that *x* = 0·4 is closer to the actual situation. This lowering of *x* can be attributed to the larger Balmer discontinuity in the Al star, with a consequent increase in the absorption coefficient in the ultraviolet. It may be pointed out here that the observed *U* flux may not originate entirely in the secondary (see the discussion of ultraviolet excess in Section 5).

3.4 *Spectral Types and Colours of the Component Stars*

Using the computed dimensions, observed fractional luminosities and the ratio of luminous efficiencies, the reflection corrections were computed and applied to the observed luminosities of the hotter and the cooler components. After converting these into magnitudes they were added to the brightness (in magnitudes) of the system at phases 0·25 and 0·75 quadratures. Thus we obtained the magnitudes and colours of each component given in Table 4. From the $(B - V)$ and $(U - B)$ colours for the hotter and cooler components thus obtained, the spectral types were read off from Allen's (1973) Table. The spectral type for the primary (hotter) component is A1 from both the $(B - V)$ and $(U - B)$ colours. As far as the secondary is concerned, the spectral class obtained from the $(U - B)$ colour came out to G8 III while that

Table 4. Spectral types and colours of component stars

Quantity	Primary	Secondary
Spectral type	A1	K1
Luminosity class	V	III
V	7·526	8·903
$B-V$	+·027	0·970
$U-B$	−·019	0·283
Distance to the system	157 parsecs	

from (B — V) is K3 III. We suspect that the U flux may not entirely originate in the secondary and that the gaseous radiating plasma around the primary may be contributing heavily to this band. This question is discussed in a greater detail in Section 5. For these reasons we fix the spectral class as Kl III for the secondary.

Using the derived spectral classes, new values of (E_c/E_h) were obtained applying Cester's (1969) tables. These improved values were used again for the computation of the reflection corrections to the observed fractional luminosities and further, the magnitudes and colours of the component stars. These new colours again gave the spectral types of Al V and Kl III which we had used for reading the E values from Cester's tables.

From the spectral type of the primary and using the spectral class—mass and the spectral class—radius relation (Allen 1973), the preliminary estimate of its mass is obtained as 3·0 $M_\odot$ and radius as 2·3 $R_\odot$. From the V magnitude and the colours, the distance to the binary system turns out to be about 157 parsecs.

4. Absolute dimensions and the model

4.1 *Masses and Radii of the Components*

As reported earlier in Paper I the absolute dimensions were computed in different ways under different initial assumptions

1. That Miller and McNamara's (1963) estimate of the mass ratio from one secondary spectrum is reasonably good,
2. That the primary is on the main sequence and follows the spectral type—mass relation (Allen 1973),
3. That the primary is on the main sequence and follows the spectral type—radius relation (Allen 1973),
4. That the secondary is filling its Roche lobe, giving us a mass ratio from Roche limit calculations of Plavec and Kratochvil (1964).

Each of these four assumptions were applied to the spectroscopic orbits given by Sahade and Cesco (1946) and by Sanford (1937). As pointed out in Paper I, Sanford's (1937) spectroscopic elements represent the evolutionary aspect of the system better than those given by Sahade and Cesco (1946). This conclusion is strengthened by the observations of Popper. According to him, the amplitude of the velocity curve of the secondary is 130 km s^{-1} while that of the primary appears to be about 35 km s^{-1}.

Popper has measured the sodium D lines for the secondary. This appears more definitive and less ambiguous compared to the case of the primary for which numerous lines in the blue region have been measured. Although the velocity curve of the primary shows a distortion in the phase range 0·2 to 0·7 due to the fact that the lines chosen for measurement do not originate wholly in the photosphere of the primary, the amplitude is not likely to be much different. Thus we obtain the mass ratio of the component stars as the inverse of the ratio of their amplitudes of velocity variation and obtain a value of $m_2/m_1 = 0{\cdot}269$.

Assuming the orbital eccentricity to be zero, which is borne out by our light curves as well as Popper's velocity curves, we obtained the absolute dimensions given in Table 5. A scale model of the system is shown in Fig. 4. It may be emphasised that the mass of the primary component derived from our observed colours as a main sequence star and that derived from Popper's observations are quite consistent.

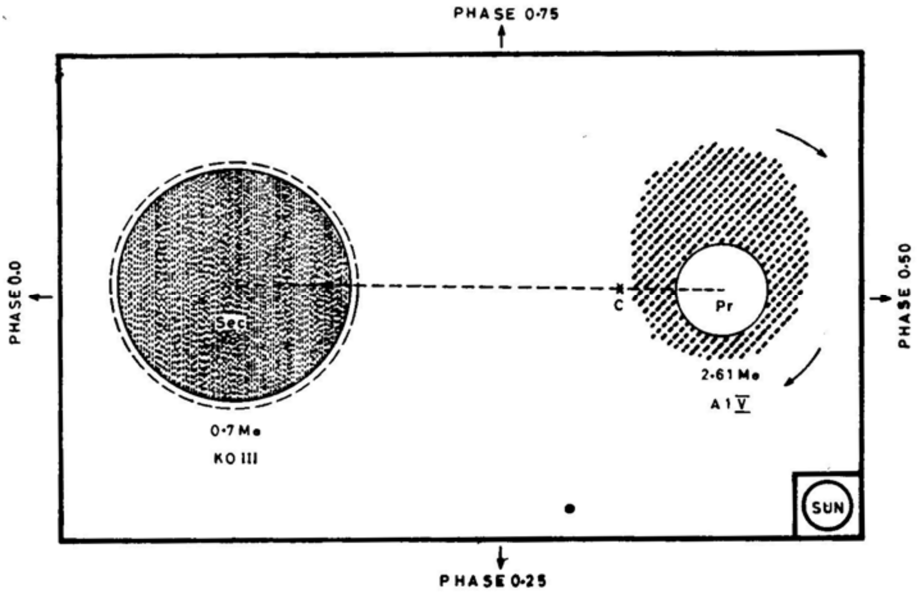

Figure 4. Scale diagram for the system of TT Hydrae based on Popper's velocity curve. The linear scale is shown by the solar diameter (7×10^5 km). C denotes the centre of mass of the system. The dashed circle around the secondary is the theoretical Roche lobe. The dimensions of the circumstellar matter around the primary is, however, not drawn to scale.

Table 5. Absolute dimensions of TT Hydrae based on Popper's* velocity curves.

mass ratio = 0·269

Physical parameter	Primary	Secondary
Mass $M_\odot$	2·61	0·70
Radius $R_\odot$	2·01	5·53
Density gm cm^{-3}	0·453	0·002
Size of the orbit (10^6 km)	3·37	12·50
Centre to centre distance (10^6 km)	15·87	

*1979, personal communication

4.2 *Comparison between the Theoretical and the Observed Fourier Coefficients*

The observed Fourier coefficients obtained by a harmonic representation of the outside eclipse normal points have contributions from the reflection effect as well as the ellipticity effect. Thus $A_i = A_i^{\text{ell}} + a_i^{\text{ref}}$ Hence we proceed as follows: (1) Using the (E_c/E_h) ratios, and the dimensions, the G_h and G_c values were computed by equation (102) of Russell and Merril (1952) which were then used to obtain C_1, C_0 and C_2 with i = 83°.74, obtained from the photometric analysis. This gives the reflection component of the Fourier coefficients. (2) The ellipticity components are computed using the formulae given by Merrill (1970). For this purpose, we adopted x = 0·6 for V and B and 0·4 for U and y = 1 for all the three filters. The coefficients were computed for the mass ratio m_2/m_1 = 0·269 for the hotter and the cooler components, and they were combined with weights proportional to the observed luminosities. (3) The ellipticity and reflection coefficients obtained from the geometrical elements and mass ratio were added and compared with the observed Fourier coefficients. As shown in Table 5 the agreement is quite good for most of the coefficients. This is an indirect proof of the validity of our solution.

The small discrepancy in computed and observed coefficients can be traced to the inclusion of sine terms in the representation of the observed light curve outside the eclipse by equation (1). In order to verify this we have calculated l (90°), the luminosity at quadrature, both from the theoretical and observed Fourier coefficients. In the first case it is given by $(A_0 - A_2 + A_4)$ while in the latter it will be equal to $(A_0 - A_2 + A_4 + B_1 - B_3)$. The computed and observed values of l (90°) are given at the bottom of Table 6, the agreement between them is remarkably good which again points to the validity of our solution.

Table 6. Comparison of theoretical and observed Fourier coefficients for TT Hydrae

$m_2/m_1 = 0{\cdot}269$

Coefficient		V	B	U
A_0	Computed	+0·97164	+0·98330	+0·98534
	Observed	+0·95762±·00115	+0·97521±·00128	+0·97672±·00168
A_1	Computed	−0·01604	−0·00961	−0·00884
	Observed	−0·01379±·00159	−0·01103±·00176	−0·01479±·00241
A_2	Computed	−0·03074	−0·01605	−0·01362
	Observed	−0·03479±·00187	−0·01635±·00204	−0·01012±·00267
A_3	Computed	+0·00087	+0·00169	+0·00217
	Observed	+0·00111±·00159	+·000153±·00177	−0·00202±·00240
A_4	Computed	−0·00635	−0·00605	−0·00703
	Observed	−0·00650±·00163	−0·00608±·00183	−0·00703±·00247
l(90°) Computed		0·99603	0·99330	0·99193
l(90°) Observed		0·99433	0·99579	0·99187

5. Problem of ultraviolet excess

The existence of the problem of ultraviolet excess in cool subgiant secondaries in Algol type eclipsing binaries is well known (Koch 1972, Hall and Garrison 1972, Devinney, Hall and Ward 1970). As noted in Section 3.4, the secondary component of TT Hydrae also exhibits an ultraviolet excess of 0·5 to 0·6 magnitudes. There are two hypotheses regarding the origin of the ultraviolet excess in Algol secondaries, one of which attributes it to the underabundance of metals in the secondary itself (Bond 1972, Sistero 1968, 1971) while the other places its origin in the circumstellar matter around the bright primary component that is not totally obscured by the large secondary even during the total phase of the eclipse of the primary (Hall 1969, Hall and Garrison 1972).

Our photometric observations of TT Hydrae in *U* and (*U*– *B*) show that the ultraviolet excess is due to asymmetric circumstellar matter around the primary, in confirmation with the results of Hall and Garrison (1972). A detailed observation of the light and colour curves shows the following features.

(1) The second contact in *U* and (*U* – *B*) is not as sharp as that in *B* and *V* filters. Moreover, it is less well defined compared to the third contact.
(2) Asymmetry in the *U* and (*U*–*B*) curves during the primary minimum from the first to the fourth contact is noticeably large.
(3) Variation of light over a few days in the total phase of the primary minimum is observed in *U,* similar to the case of U Cep (Huffer and Code 1959).
(4) The ultraviolet excess manifests itself well after the first contact and is restored well before the fourth contact.

There is also supporting spectroscopic and Polarimetric evidence from earlier and recent observations.

(1) Hα-emission lines appear redshifted just before the totality begins and violet-shifted just after the totality ends (Wyse 1934; Sahade and Cesco 1946). The lines are otherwise in 'normal' position during the total phase.
(2) Distortion is present in the velocity curve of the primary component as compared to the essentially sinusoidal nature of the secondary velocity curve. Popper's velocity curve of the primary shows a blueward shift of the lines used for its measurement from phase 0·2 to 0·7.
(3) Popper also notes that the lines of Mg II and Si II are essentially absent and that the intensity of all lines shows large variations.
(4) About 1 to 2 per cent polarisation during the totality has been reported by Serkowski (1970).

We therefore propose that the extra light at the second contact in *U* filter, compared to that at the third contact may be due to the asymmetric distribution of matter around the primary as shown in Fig. 4. An excess which is entirely due to the secondary will not exhibit any asymmetry in the light or the colour curve. Secondly, the excess cannot vary if it were intrinsic to the secondary component. We observe a change of about 0·07 mag in the excess within a few days (our observational error is $\leqslant$ 0·02 mag). Thirdly, the excess should change continuously from the first to the fourth contact, whereas our observations show to the contrary. The excess shows itself well after the first contact and is restored well before the fourth contact. All these photometric features lead to the conclusion that the origin of the ultraviolet excess is not intrinsic to the secondary and that it must be due to the circumstellar matter (thick ring or disk) around the primary. Further, we also conclude that the distribution of matter around the primary is asymmetric. The circumstellar matter becomes photometrically conspicuous in *U* band when most of the light from the bright primary is cut off during an eclipse. It is due to this reason that our attemped solution of the *U* light curve gave the ratio of radii as 0·4075 in comparison to 0·3812 (mean) for *B* and *V* filters (see Section 4.1 and 4.2). The overall picture is very similar to U Cep (Batten 1974) in many respects. SW Cyg (Hall and Garrison, 1972) is yet another Algol system showing similar behaviour.

The spectroscopic features also very clearly indicate that there is matter around the primary and that it is observable even during totality. The abundance analysis of the subgiant secondary of U Cep (Algol type eclipsing binary with B7 V + G8 III-IV) has been recently reported by Parthasarathy, Lambert and Tomkin (1979). They have obtained high dispersion (1·9 Å mm^{-1}) spectra in the near infrared region, which is much less contaminated by any emission from the circumstellar matter in the system. They find the composition to be normal within the limits of observational errors. However, Naftilan (1975) reports [Fe/H] = – 0·3 for TT Hya, indicating a mild underabundance. His spectra are obtained at a rather coarse dispersion of 125 Å mm^{-1} and are not good enough for abundance analysis (Parthasarathy 1979, personal communication). Parthasarathy, Lambert and Tomkin (1979) find that the cores of Ca II triplets in the infrared are very weak for the secondaries of U Cep and U Sge in comparison with the standard stars. Baldwin (1973) reported that the Ca II K lines in the spectrum of U Cep to be somewhat filled in by emission. Since the H and K line emission intensity is found to be an indicator of chromospheric activity (Wilson and Bappu 1957; Wilson 1963) and the Ca II H and K lines and the Ca II infrared triplet have the same common upper state, we conclude that the secondaries of Algols might have active chromospheres. This might explain a part of the ultraviolet excess observed in their atmospheres.

6. Discussion and conclusion

The theoretical computation of the fractional radii of the secondary for given mass ratios (Plavec and Kratochvil, 1964) is used for computing the size of the Roche lobe. For the observed ratio of 0·269, the fractional radius turns out to be 0·264 whereas the observed value given in Table 5 is 0·2438. This indicates that the secondary has not filled its Roche lobe, and thus the system is an undersize subgiant. The primary appears to be a normal main sequence star (Al V)in every respect *i.e.* from its photometric colours, the radius and the mass. However, the secondary has not filled its Roche lobe as the theory of mass transfer and the accepted theory of stellar evolution requires. Still about 10 per cent of the secondary Roche lobe remains to be filled during its evolution off the main sequence.

The above conclusion may not be valid if the derived mass ratio and radii of the components are not correct, which may very well prove to be the case. We do not really understand just where the primary lines are formed on account of their variable intensities and clear evidence of dilution. There is also some uncertainty in the radii. We estimate that our value of k = 0·3812 is fairly well determined within an error of ± 0·0012. The corresponding error in r_g = 0·2438 will be about ± 0·0008. If the Roche lobe of the secondary is to be filled completely, the mass ratio should lie between 0·202 and 0·208. We do not believe that the spectroscopic data can be reconciled with such low values of mass ratio. Hence, it is quite likely that the secondary does not fill its Roche lobe. Anyway taking the values of the mass ratio and radii at their face value we may consider the possibility of TT Hydrae being a very young system with its secondary still in the pre-main sequence stage of evolution. Then using the evolutionary calculations of Iben (1965) we get a thermal contraction time of 2×10^6 years for the primary which has a mass of 2·6 $M_\odot$. For this mass, the main sequence lifetime is 2×10^8 years, while we obtain the contraction time of 7×10^7 years for the secondary with 0·7 $M_\odot$ Thus, we think the age of the system is of the order of about 5×10^7 years with the secondary in some sort of T Tauri phase. Further observations would be necessary to confirm these conclusions by placing more stringent limits on the radii of components.

It may be mentioned that one needs to explain the origin of the circumstellar matter around the primary if the secondary is not filling its Roche lobe and hence not transferring mass to the primary. It is not wrong to assume that the young binary may still have some remnant of the original gas cloud which is now being slowly accreted by the more massive primary component. The variation of intensities and dilution effect in the lines of the primary as well as the ultraviolet excess may be manifestations of interaction of this matter with the photosphere.

Our observations indicate that the orbit is circular. As is evident from the light curves, a better photometric confirmation for the circularity of the orbit is possible only through low frequency filters like red and infrared. Hence we recommend observations of the secondary minima in these filters. An important conclusion we draw from our studies regarding the choice of photometric bands is that any band shortward of 4000 Å is not quite representative of the orbital features of the system. Therefore one has to exercise enough caution in using U magnitudes for an analysis of the orbit.

In recent years, TT Hya has also been observed in the radio region. Altenhoff *et al.* (1976) place an upper limit to the radio emission as 10 mJy at 10·69 GHz on 16th June 1973. Plavec (1977, personal communication) reports the appearance of shell lines. Peters and Polidan (1976) report cyclic variation in V/R for this system. Bidelman (1976) has listed this system as an early type shell star. All this work indicates that the system is not a simple one and there are many spectroscopic peculiarities and complications.

Detailed spectroscopic investigation of the secondary is possible for this system with the use of modern detectors and techniques. The duration of totality is also fairly large (6 hours) to give uncontaminated spectra of the secondary. One can also study the spectral features of the circumstellar matter around the primary. We also suggest photometric observations of the secondary in the red and infrared in order to improve the photometric elements, particularly to confirm the circularity of the orbit. Ultraviolet observations during the primary minimum from space vehicles might give important information regarding the unstable ring/radiating plasma in the system.

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