ABSOLUTE DIMENSIONS OF TT HYDRAE

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Abstract. The photometric elements of the Algol type binary TT Hydrae derived by the authors from their *UBV* observations during 1973–77 have been combined with the spectroscopic elements given by Sanford (1937) and Sahade and Cesco (1946) to obtain the absolute dimensions of the system. It is found that the spectroscopic orbital elements given by Sanford represent the evolutionary status of the secondary component better than those of Sahade and Cesco. The primary appears to be an Al v main sequence star of mass ~ 3 to $4\mathfrak{M}_{\odot}$ and radius $\sim 2.3R_{\odot}$. The secondary fills its Roche lobe; it can be represented by a K0 III star of mass $\sim 0.8\mathfrak{M}_{\odot}$ and radius $\sim 6.0R_{\odot}$. Better spectroscopic data are needed for confirmation of these results.

1. Introduction

Binary stars give us fundamental information about the masses and radii of stars, which form the basis of all theories of stellar structure and evolution. The Algol type binaries have become particularly important during the last two decades as their evolution is governed by the process of mass transfer between the two components.

TT Hydrae is a typical Algol system with a primary component which is variously classified as a main sequence star of spectral type B9 to A3, and it shows Hα emission during and near the primary eclipse phases. Since only a photographic light curve and its solution by Shapley (1927) were available, the binary was put on the observing programme of the 48-inch telescope of Japal-Rangapur Observatory for obtaining photoelectric light curves in the Standard UBV colours. The coverage of all the phases of the system is difficult on account of its period being close to seven days. In fact we can observe the primary eclipse in one year and the secondary eclipse the next from the same observing station. In all, we observed the star on 63 nights during the four years from 1973 to 1977 obtaining about 900 points in each of the three colours. The observations are given in a contribution from our observatory by Kulkarni and Abhyankar (1978).

2. Photometric Results

As reported earlier (Kulkarni and Abhyankar, 1977) our light curves showed a shift of +0.0060 P with respect to Reilly's (1946) epoch (HJD 2424615.388) and period (6.9534124 days), which gave an improved period of 6.9534284 days. A more careful averaging of the descending and ascending branches of the flat primary minimum has

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given a further shift of +0.000277 P so that the period is now modified to 6.95342913 days. The new ephemeris would then be given by

$$\text{Primary Minimum} = \text{HJD } 2424615.388 + 6.95342913 \text{ E}.$$

The light curves drawn in Figures 1 and 2 show a deep flat primary eclipse and a very shallow secondary eclipse which is easily seen in *V* colour and is progressively less prominent in *B* and *U*. It is obvious that the primary eclipse corrresponds to the occultation of a small hot star by a larger and cooler star of much less surface brightness.

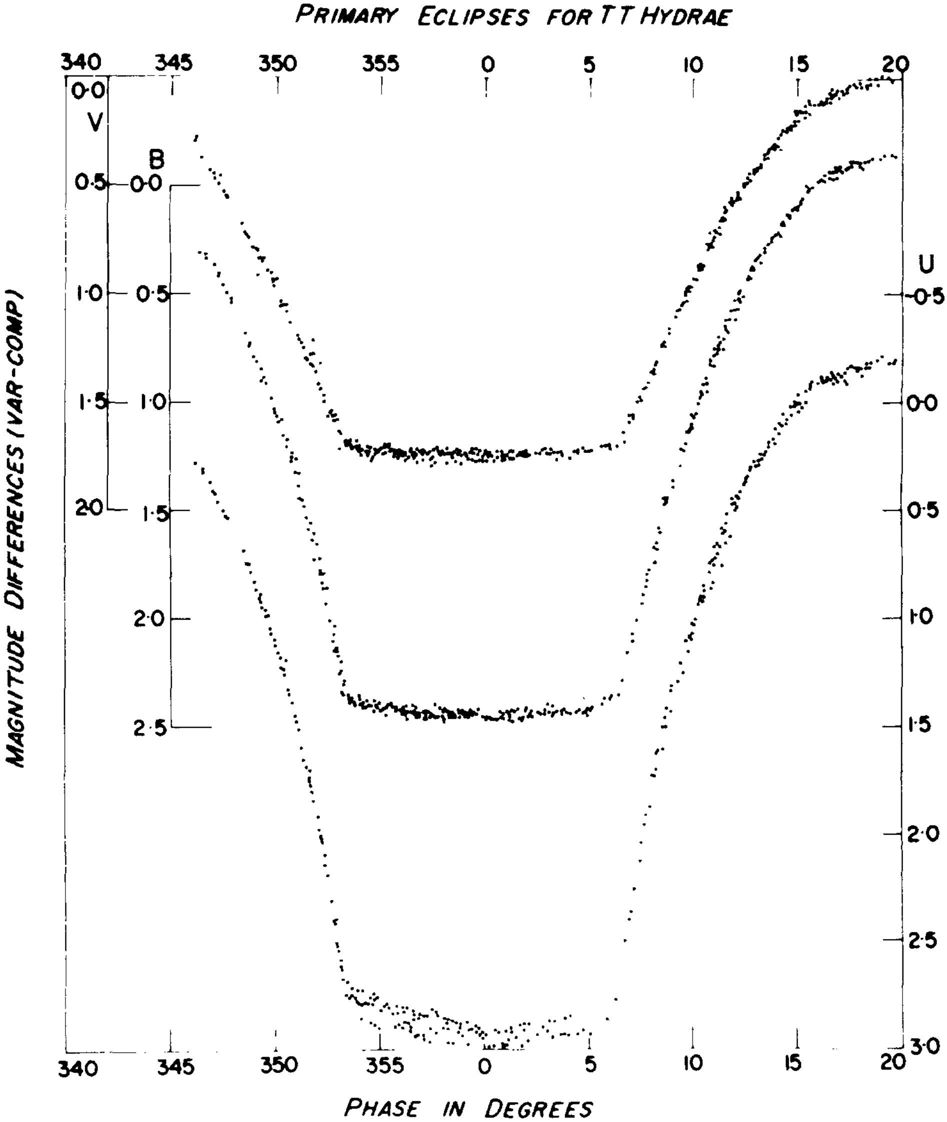

Fig. 1. The primary eclipse of TT Hydrae in *V*, *B* and *U* (range in phase: 0 ± 20°).

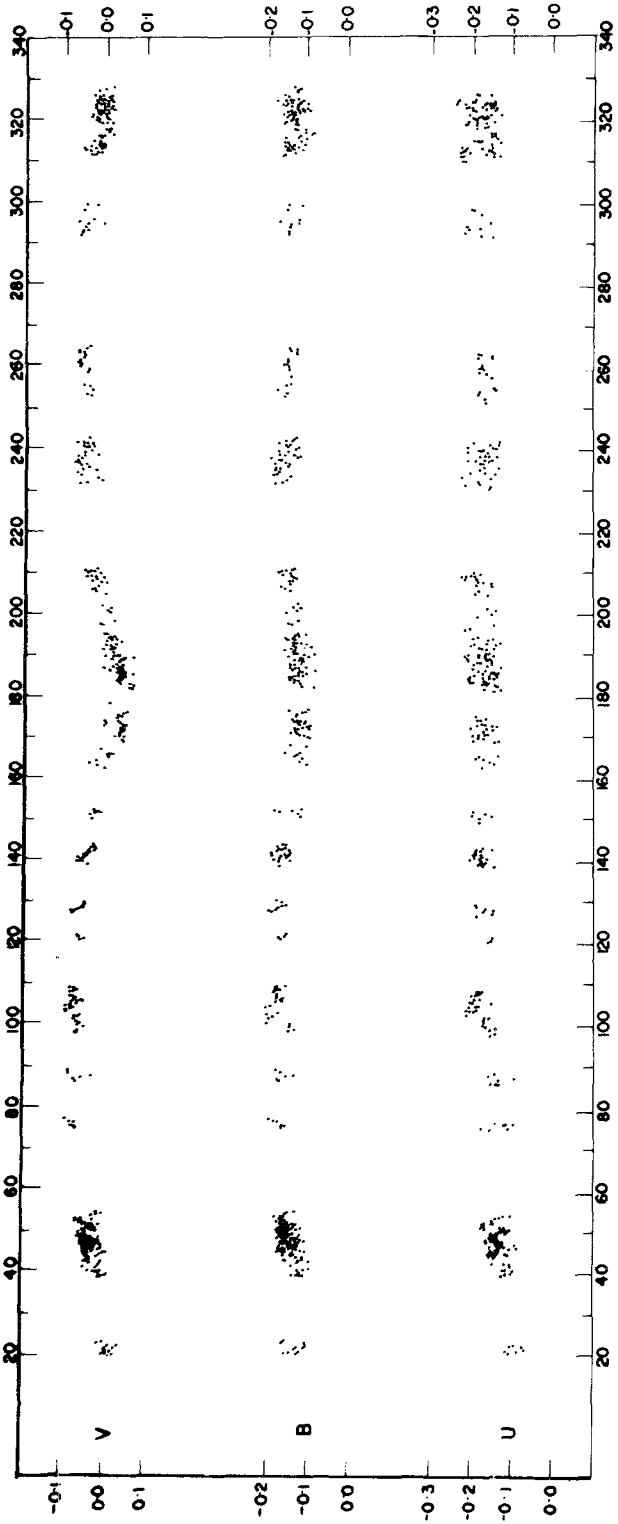

Fig. 2. The rest of the light curve of TT Hydrae in *V*, *B* and *U* (range in phase: 20° to 340°).

TABLE I

Photometric Orbital Elements of TT Hydrae

Element	Present study	Shapley (1927)
Θ_e	$18\overset{\circ}{.}55$	
$X_s(V, B)$	0.6	
$X_g(V, B)$	0.8	
$X_s(U)$	0.4	
k	0.3812	0.30
j	$83\overset{\circ}{.}74$	$82\overset{\circ}{.}6$
r_g	0.2438	0.240
r_s	0.0930	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	
$J_s/J_g(U)$	$\sim$200	

After rectification by the Russell and Merrill (1952) method the depth of the primary eclipse directly gives L_s and $L_g = 1 - L_s$. In order to obtain the remaining elements we used Kopal's (1959) first method for total eclipses. For each assumed value of k, the ratio of the radii of the components, we obtain the set of elements r_g and i and represent the light curve by these elements. On forming the sums $\sum W_i(\mathrm{O} - \mathrm{C})_i^2$ with $W_i = n_i/l_i^2$, where n_i = number of observations combined in the normal point and l_i = observed light, and plotting them as a function of k it was found that the weighted sum of the residual (in light) squares was minimum for $k = 0.3812$. The same value of k was also found to represent the secondary eclipse in V colour. The resulting elements are given in Table I along with the elements found by Shapley (1927). The details of the procedure adopted by us will be published elsewhere.

3. Spectroscopic Information

From the values of L_s and L_g in various colours, as given in Table I, and the values $V = 7.339$, $B - V = +0.268$ and $U - B = +0.069$ for the comparison star HD 97111 observed by us, we obtain the magnitudes, colours and spectral types of the two components given in Table II. The derived spectral type Al v for the primary is in agreement with earlier classification of that star. The spectroscopic parallax gives a distance of 157 pc for the system; interstellar reddening would be negligible at this distance. Then, using the spectral type-mass and spectral type-radius relations for Main Sequence stars (Allen, 1973), we have a preliminary estimate of mass and radius

TABLE II

Colours and Spectra of Components

Quantity	Primary	Secondary
V	+7.528	+8.903
$B - V$	+0.027	+0.970
$U - B$	−0.019	+0.283
Spectral type	A1 V	K0 III

of the primary as $\mathfrak{M}_1 = 3.0\mathfrak{M}_\odot$ and $R_1 = 2.3R_\odot$. The spectral type K0 III* and $R_2 = 6.0R_\odot$, as obtained from k, for the secondary clearly indicate that the less massive secondary is an evolved star which has lost mass and is most probably filling its Roche lobe.

In order to verify the above results we have to combine our photometric results with the elements of the spectroscopic orbit derived by Sanford (1937) and Sahade and Cesco (1946). Their main results are given in Table III. The last two rows of the table give a_1 and $\mathfrak{M}_2^3/(\mathfrak{M}_1 + \mathfrak{M}_2)^2$ obtained by using our value of $i = 83.^\circ74$. Since the hydrogen lines are likely to be contaminated by emission, the elements derived from it by Sahade and Cesco – column (3) of Table III – will not be reliable as can be seen from the high value of eccentricity obtained therefrom. Our light curves show that the secondary eclipse occurs at phase 180° corresponding to $e = 0$. We shall, therefore, ignore the H line solution in further discussion.

TABLE III

Spectroscopic Orbits of TT Hydrae

	Sanford (1937)	Sahade and Cesco (1946)	
		Ca II K	H
Element	(1)	(2)	(3)
$a_1 \sin i$ (10^6 km)	3.07	3.9	4.3
$f(m)$	0.024	0.05	0.07
e	0.08	0.12	0.24
† a_1 (10^6 km)	3.09	3.92	
† $\mathfrak{M}_2^3/(\mathfrak{M}_1 + \mathfrak{M}_2)^2$	$0.0244\mathfrak{M}_\odot$	$0.0509\mathfrak{M}_\odot$	

† These quantities are obtained by inserting our value of $i = 83.^\circ74$.

* The $(B-V)$ colour of the secondary corresponds to the spectral type K3 while the $(U-B)$ colour corresponds to the spectral type G8. Therefore, we have adopted K0 as the mean spectral type of the secondary.

Miller and McNamara (1963) had obtained a spectrum of the secondary from which they inferred a mass ratio $\mathfrak{M}_2/\mathfrak{M}_1 = 0.174$. Inserting this mass ratio in the solution given by Sahade and Cesco for Ca II K line – column (2) of Table III – we find $\mathfrak{M}_1 = 13.2\mathfrak{M}_\odot$ and $\mathfrak{M}_2 = 2.3\mathfrak{M}_\odot$. These masses are too large for both the components, particularly for the primary which is found to be an A1 V star. If we use the orbital data of Sanford along with Miller and McNamara's mass ratio, we obtain $\mathfrak{M}_1 = 6.36\mathfrak{M}_\odot$ and $\mathfrak{M}_2 = 1.11\mathfrak{M}_\odot$, which are in better agreement with the spectral type of the primary; but they are still larger than expected. Miller and McNamara's mass ratio, based on only one measurement, is obviously unreliable. Anyway, Sanford's elements seem to be physically more significant, and in that case the value of the eccentricity is also closer to zero as found by us.

4. Absolute Dimensions

It is now possible to delimit the absolute dimensions of the system on the basis of our photometric orbital elements. We can proceed in three ways as follows:

(i) From the spectral type-mass relation for the primary estimate $\mathfrak{M}_1 \rightarrow \mathfrak{M}_2$ from $f(\mathfrak{M}) \rightarrow \mathfrak{M}_2/\mathfrak{M}_1 \rightarrow a_2 \rightarrow a \rightarrow R_g$ from r_g and R_s from k. The mass ratio also gives the Roche lobe radius r_g^*.

(ii) From the spectral type-radius relation for the primary estimate $R_s \rightarrow R_g$ from $k \rightarrow a$ from r_g and $a_2 \rightarrow \mathfrak{M}_2/\mathfrak{M}_1 \rightarrow \mathfrak{M}_1, \mathfrak{M}_2$ and r_g^*.

(iii) Assume that the secondary fills its Roche lobe; then $r_g = r_g^*$ gives $\mathfrak{M}_2/\mathfrak{M}_1$ from which all other parameters follow.

The parameters of the two components of TT Hydrae obtained in this way are given in Table IV(a) and (b) for Sahade and Cesco's (Ca II K) and Sanford's elements, respectively. An inspection of Table IV(a) shows that the first two procedures give a mass ratio of about 0.3 and make the size of the secondary smaller than its Roche lobe. Thus the two components would form a detached system and the advanced evolution of the secondary would be difficult to understand. If, on the other hand, we assume that the secondary fills its Roche lobe, then the primary comes out to be too massive ($\mathfrak{M}_1 = 8.6\mathfrak{M}_\odot$) for its spectral type (A1 V).

However, the calculations of Table IV(b) show that we get fairly consistent parameters if we adopt Sanford's spectroscopic elements. In that case $\mathfrak{M}_2/\mathfrak{M}_1$ lies between 0.20 and 0.23 and the absolute dimensions of the two components are inferred to be:

$$\mathfrak{M}_1 = 3 \text{ to } 4\mathfrak{M}_\odot, \qquad R_1 = 2.3R_\odot$$

$$\mathfrak{M}_2 = 0.70 \text{ to } 0.85\mathfrak{M}_\odot, \qquad R_2 = 6.0R_\odot.$$

5. Conclusion

In summary, TT Hydrae is an Algol system with a main Sequence primary of spectral type A1 V and an evolved secondary of spectral type K0 III which fills its Roche lobe.

TABLE IV(a)

Absolute parameters of TT Hydrae from the orbit by Sahade and Cesco (1946)

Physical parameter	Spectra-mass relation	Spectra-radius relation	Secondary fills Roche lobe
$\mathfrak{M}_1$	**2.951**	3.546	8.635
$\mathfrak{M}_2$	0.912	1.020	1.766
$\mathfrak{M}_2/\mathfrak{M}_1$	0.309	0.288	0.205
a_1 (10^6 km)	3.923	3.923	3.923
a_2 (10^6 km)	12.697	13.640	19.185
a (10^6 km)	16.620	17.563	23.109
R_g (10^6 km)	4.052	4.282	5.634
R_s (10^6 km)	1.544	1.632	2.147
$R_s/R_\odot$	2.21	**2.35**	3.07
r_g^*	0.274	0.269	**0.244**
r_g	0.244	0.244	0.244

Note: Bold faced figures are the starting points of calculation for each column.

TABLE IV(b)

Absolute parameters of TT Hydrae from the orbit by Sanford (1937)

Physical parameter	Spectral-mass relation	Spectral radius relation	Secondary fills Roche lobe
$\mathfrak{M}_1$	**2.951**	3.703	4.144
$\mathfrak{M}_2$	0.685	0.790	0.847
$\mathfrak{M}_2/\mathfrak{M}_1$	0.232	0.213	0.205
a_1 (10^6 km)	3.088	3.088	3.088
a_2 (10^6 km)	13.306	14.475	15.102
a (10^6 km)	16.395	17.563	18.191
R_g (10^6 km)	3.997	4.282	4.343
R_s (10^6 km)	1.523	1.632	1.690
$R_s/R_\odot$	2.18	**2.35**	2.41
r_g^*	0.253	0.247	**0.244**
r_g	0.244	0.244	0.244

Note: Bold faced figures are the starting points of calculation for each column.

It is rather surprising that Sanford's orbit based on only 16 plates represents the evolutionary aspect of the system better than Sahade and Cesco's orbit based on numerous measurements. As pointed by Sahade and Cesco, Ca II K radial velocity curve may be subject to distortions produced by the presence of gas streams and hence it may give spurious results. Sanford's radial velocities appear to be based on measurement of several lines. It is, therefore, necessary to obtain more reliable spectroscopic data for verification of the tentative results given here. We understand that Dr M.

Plavec and Dr D. M. Popper have obtained spectra of this interesting binary. We look forward to their study for validation of our results.

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