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TW Andromedae - improved elements

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Abstract. A solution of the v and b light curves of the semidetached eclipsing binary system TW And, obtained by Amman and Walter (1973), using W-D method, keeping $T_{c,h}$ (7200°K) and q(0.1928) as fixed parameters yielded improved absolute elements. They are: R_h=2.19±0.05$R_\odot$, R_c=3.37±0.10$R_\odot$, Log $L_h/L_\odot$ =1.0625±0.1568, Log $L_c/L_\odot$=0.4973 ± 0.1554, $M_h/M_\odot$=1.677±0.070, $M_c/M_\odot$ =0.323±0.025 From the position of the primary component of this binary on the evolutionary tracks of stars of Pop I composition computed by Maeder and Meynet (1988), it is noticed that this component is evolving along the track of a 1.7$M_\odot$ star. Since the mass of the primary itself is 1.7$M_\odot$, it is concluded that the mass accrued by the primary, if any, had no effect on its evolution.

Key words: eclipsing binaries–semidetached–TW And–elements-individual

1. Introduction

The eclipsing binary nature of TW Andromedae (BD +32°4756, P = 4.12 days) was first detected by Kopff (1909). Since this is a totally eclipsing system, it evinced much interest. Dugan (1933) published photoelectric observations of this system, but, because of the scantiness of observations outside the eclipses, these light curves could not yield any additional information regarding the distortions suspected earlier in the light curves of the system.

Spectroscopic studies of TW And were reported by Hiltner et al.(1949) who derived an eccentric as well as a circular orbit from this data. However, a rediscussion of this study by Lucy and Sweeny (1971) suggested a lower probability for the eccentric orbit and it was suspected that the measures of spectral lines, from which the radial velocities were derived, might have been influenced by gas streams in the system.

Amman and Walter (1973) observed this binary photoelectrically and solved their light curves (v and b pass bands) using the method of Russell and Merrill (1952). They used a particular method for rectification and adopted a third light of about 2-5% of the total light ($L_h+L_c+l_3$), in the form of hot spots, for their analysis. Mezzetti et al. (1980) reanalysed the data of Amman and Walter using Wood's WINK programme. Their solution with a circular orbit, yielded similar photoelectric elements without the use of a third light,l_3. However, since no spectroscopic mass-ratio was available to them, for obtaining this parameter they used the mass function f(m) of Hiltner et al.(1949) and assumed the main sequence nature for the primary component from which they could approximate its mass, M_1. Since some of the primaries of the semidetached systems do not behave similar to their main-sequence counterparts, the mass-ratio derived in the above manner would not be very accurate.

For the first time, Popper(1989) published the radial velocity curves of both the components of TW And and derived a most reliable mass-ratio of 0.193 for the system. Since an improved mass-ratio is now available and as Wilson-Devinney (1971) synthetic light curve method (W-D) is the most widely used, we reanalysed the v and b light curves of Amman and Walter(1973) with this method. In the following we give the results of these analyses.

2. Methodology

As already mentioned, we used Wilson-Devinney method(1971) for solving the light curves of TW And that were published by Amman and Walter(1973). This data consisted of 246 yellow(531nm) and 243 blue(433nm) observations on their instrumental system and we used all these individual observations for our analysis. Even though the analysis of observations in any instrumental system does not permit one to get the magnitudes and colours of the individual components, one can get geometric elements and through them the absolute elements.

For initiating the W-D method, one needs reliable preliminary elements. For this purpose we used the values of the required parameters given by Mezzetti et al.(1980). According to Hiltner et al. (1949) and Wood et al. (1980) the spectral type of the primary hotter component is FOV which suggests a temperature $T_{c,h}$, of 7200 K (Allen 1976; Popper 1980; Schmidt-Kaler 1982). Mezzetti et al. (1980) derived a temperature $T_{c,h}$, of 7200±25K for this component. Keeping in view the uncertainties involved, we assumed a temperature, $T_{c,h}$, of the hotter component to be 7200±200K and kept this as a fixed parameter throughout our analysis. This error of about 200K in $T_{c,h}$, may in turn entail an error of about 50K in the derived temperature, $T_{c,c}$ of the cooler component. The mass-ratio, q, of 0.1928 of this system, as given by Popper(1989), was also kept as a fixed parameter throughout the analysis. It is expected that the analysis of the light curves with fixed $T_{c,h}$ and q at known values should yield most reliable elements. According to the principles of W-D method, we adjusted the following parameters: the inclination, i; the surface potentials of the two components Ω_h, and Ω_c; the relative monochromatic luminosity of the hot component L_h, the temperature of the secondary component $T_{c,c}$ and the third light l_3. The limb darkening coefficients x_h and x_c and the albedo of the cool component A_c were treated as variable parameters. The albedo of the hotter component A_h and the gravity darkening coefficients of the hotter and cooler components G_h and G_c were kept constant. Atmospheric

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models of Kurucz(1979) and effective wavelengths, appropriate for the component temperatures(Allen 1976), of each band, were used in the analysis. The initial parameters are given in column 2 of Table 1. As it is now established (Popper 1989) that TW And is a semidetached system, we used code-5 of W-D method meant for semidetached systems. Sufficient number of runs of the DC programme was made till the sum of the residuals $\Sigma\omega$ (O-C)^2 showed a minimum and the corrections to the parameters became smaller than their probable errors. In order to check the internal consistency of the results (Popper 1984) separate solutions for each of the v and b light curves were made. These results are given in columns 3 and 4 of Table 1. In both the solutions, the third light l_3 was absent.

Table 1. TW And: Results of the analysis of the individual light curves obtained from the W-D method.

Parameter		Initial values	Individual solution		Combined solution	
			v	b	v	b
1		2	3	4	5	6
$^*T_{e,h}$K		7200	7200	7200	7200	
$T_{e,c}$K		4875	4203	4163	4191±59	
*q		0.1928	0.1928	0.1928	0.1928	
i°		86.9	87.407	87.395	87.37±0.08	
r_h	pole	0.152	0.1619	0.1604	0.1604±0.0013	
	point		0.1626	0.1610	0.1610±0.0014	
	side		0.1623	0.1608	0.1608±0.0015	
	back		0.1625	0.1610	0.1610±0.0014	
r_c	pole	0.239	0.2304	0.2304	0.2304±0.0032	
	point		0.3381	0.3381	0.3381±0.0036	
	side		0.2397	0.2397	0.2391±0.0032	
	back		0.2720	0.2720	0.2720±0.0034	
L_h/L_h+L_c		0.660(v) 0.673(b)	0.8209	0.9010	0.8206	0.9011
L_c/L_h+L_c		0.340(v) 0.327(b)	0.1791	0.0990	0.1794	0.0989
l_3		0.0	0.0	0.0	0.0	0.0
x_h		0.58(v) 0.75(b)	0.554	0.760	0.554	0.760
x_c		0.75(v) 0.90(b)	0.735	0.947	0.735	0.947
$^*A_h$		1.0	1.0	1.0	1.0	1.0
A_c		1.0	0.5	0.5	0.5	0.5
$^*G_h$		0.25	0.25	0.25	0.25	0.25
$^*G_c$		0.08	0.08	0.08	0.08	0.08

* Fixed parameters

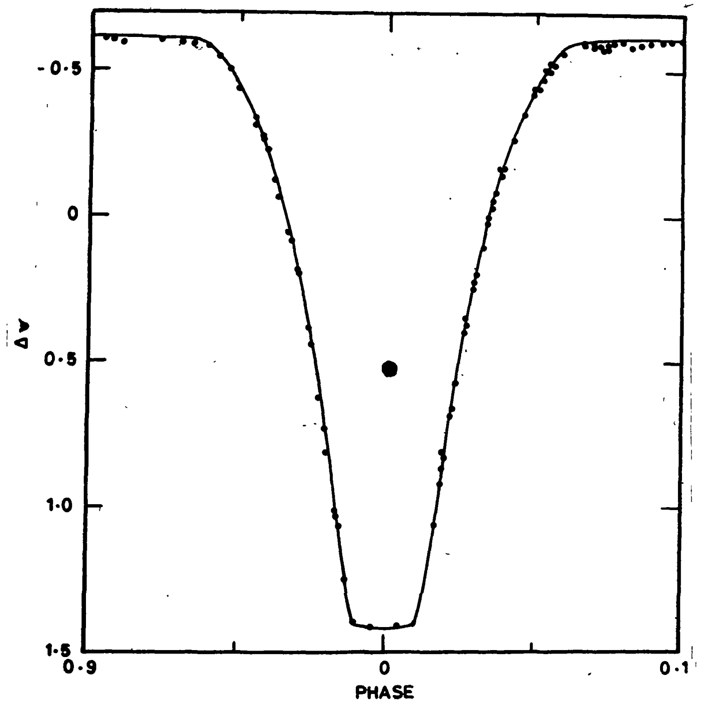

Figure 1 (a). TW And: Light curve of the primary eclipse in yellow during phases 0.9 to 0.1. Solid line represents the theoretical curve obtained from the parameters of the combined solution given in table 1. Filled circles represent the observations on the instrumental system.

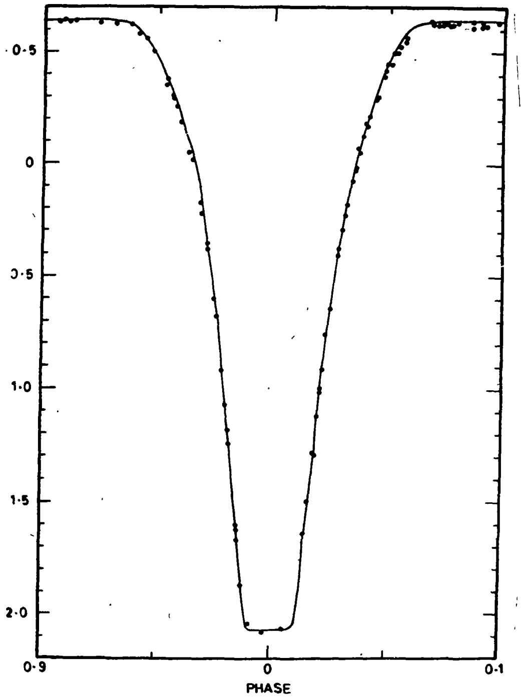

Figure 1 (b). TW And: Same as figure 1 (a) for blue.

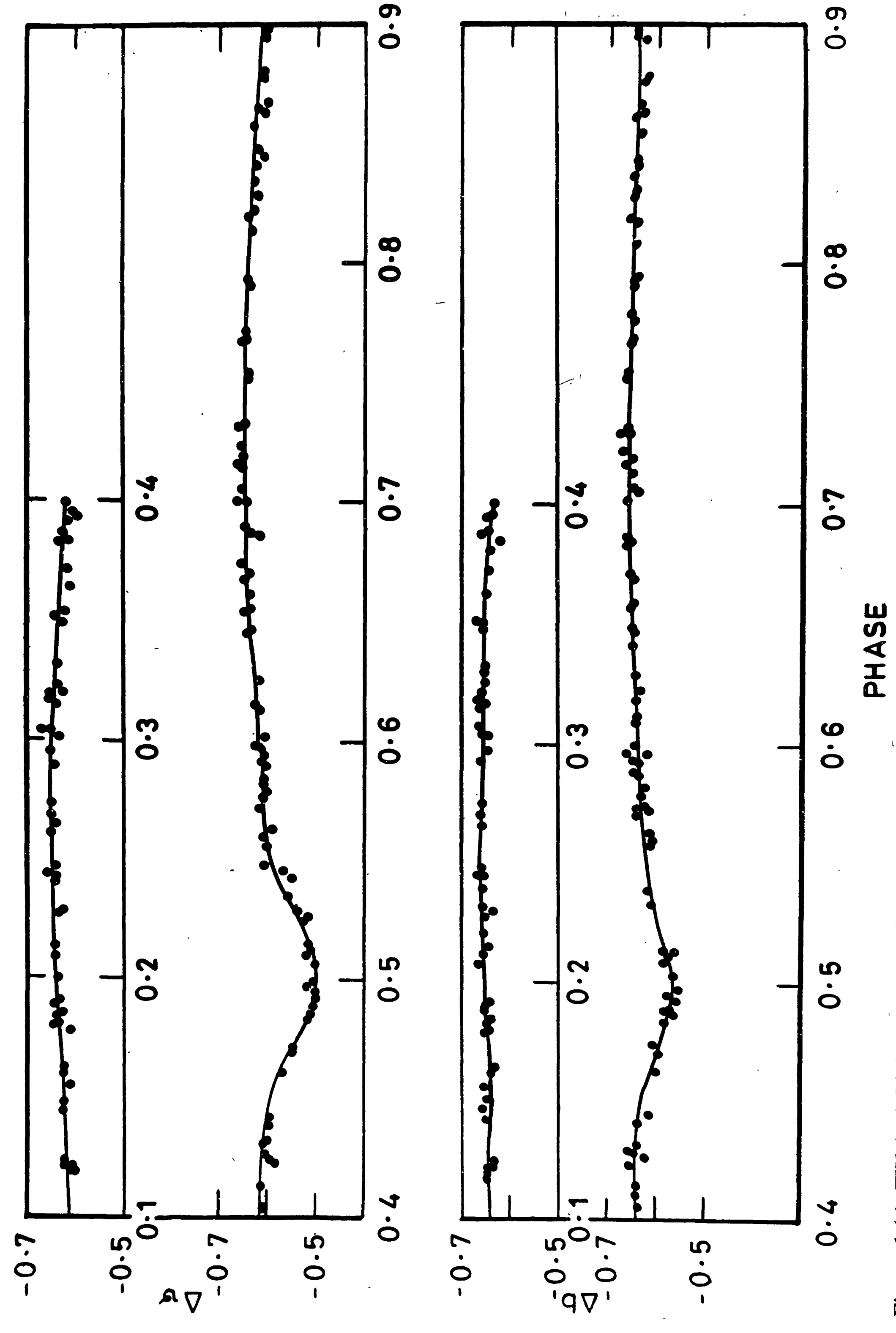

Figure 1 (c). TW And: Light curves in yellow and blue during phases 0.1 to 0.4 and 0.4 to 0.9. Solid lines and filled circles represent the same as in figure 1 (a).

As it is noticed that the individual solutions of the light curves yielded consistent results for all the parameters, another solution was made for the combined v and b light curves. For this combined solution we used the average values of i, $T_{c,c}$ r_h and r_c obtained from the individual solutions as initial elements. The parameters $T_{c,h}$, q, A_h, A_c, G_h G_c, x_h and x_c were all treated as fixed. The final elements obtained from this solution are given in columns 5 and 6 of Table 1. It is noticed that the third light l_3 is absent even in this solution. The theoretical curves obtained for v and b passbands from the elements of the combined solution are shown as solid lines in Figs la to lc. In this figure the filled circles represent the individual observations of Amman and Walter(1973). The fit of the theoretical curves to the observations is quite satisfactory.

3. Absolute elements

Since the published observations were in the instrumental system, we could not derive the magnitudes, colours and spectral types of the individual components. However, according to Hiltner et al.(1949) the spectral type of the primary is FO V and that of the secondary is KO. From the temperature of 4190° K derived for the secondary component from our combined solution and its size (see the following), we derived a spectral type of K1-3III-IV for the secondary (Popper 1980; Schmidt-Kaler 1982; Allen 1976). Combining the amplitudes of the radial velocity curves of K_1=27.0±1.5 km/sec and K_2=140±2 km/sec and P=4.12276035days (Popper 1989) with the required parameters from columns 5 and 6 of Table 1 and using the relevant equations, we obtained the absolute elements of the primary and secondary components. These values, with their errors are:

	Hot component		Cool component
$A/R_\odot$		13.64±0.22	
$M/M_\odot$	1.677±0.070		0.323±0.025
$R/R_\odot$	2.19±0.05		3.37±0.10
$\log L/L_\odot$	1.062±0.157		0.497±0.155
M_{bol}	2.03±0.39		3.45±0.39
M_v	2.02		2.81

The bolometric corrections have been taken from Popper(1980). In deriving the errors in the luminosities, we used $\Delta T_{c,h}$ = 200K and $\Delta T_{c,c}$ = 100K. For the sake of comparison, the elements of TW And as derived by Amman and Walter (1978), Mezzetti et al. (1980) and by us are given in Table 2.

Table 2. TW And: Elements obtained from different studies.

Parameter	Amman & Walter (1975) Method 1	Mezzetti et. al. (1978) Method 2	Present studies Method 3
$T_{c,h}$K	-	7200	7200
$T_{c,c}$K	-	4875	4191
q	-	0.19	0.1928
i^{0}	87.0	86.9	87.37
r_h	0.1627	0.1520	0.1607
r_c	0.2465	0.2366	0.2474
Log $L_h/L_\odot$		1.12	1.06
Log $L_c/L_\odot$		0.82	0.49
$M_h/M_\odot$		2.4	1.68
$M_c/M_\odot$		0.5	0.32
$R_h/R_\odot$		2.35	2.19
$R_c/R_\odot$		3.64	3.37
Sp.type(Pri)		FO V	FO V
(Sec)		KO	K1-3III-IV

Method: 1. Russell-Merrill 2. Wood's WINK 3. Wilson-Devinney

4. Evolution

With a view to study the evolutionary status of both the components of TW And, we plotted their positions(with error bars) on the LogM/$M_\odot$ vs Log R/$R_\odot$, Log T_c and Log L/$L_\odot$ (Fig. 2) as well as on the Log L/$L_\odot$ vs Log T_c (HR diagram)(Fig. 3) relations of the main sequence stars(Allen 1976). From Fig. 2 one can see that the primary component is slightly bigger but normal in luminosity and temperature for its mass. The secondary component is seen to be bigger, hotter and overluminous for its mass. Fig. 3 indicates that while the primary component is near but above the main sequence (brighter by about $0^m.6$) the secondary is far above the main sequence and is overluminous by about $3^m.0$ In a similar study, Sarma et al. (1995) reported that both the components of the semidetached system R CMa are overluminous, oversized and hotter for their masses. Further, they found that while the primary of R CMa is still near or on the main sequence(HR diagram), its secondary has left the main sequence and is overluminous. In the case of two other semidetached systems, TT Hya (Vivekananda Rao and Sarma 1994) and HU Tau (Parthasarathy et al. 1995) the primaries were found to be underluminous and cooler for their masses and the secondaries were found to be overluminous. It thus appears that while the secondaries of the semidetached systems have similar properties, the primaries have varied properties.

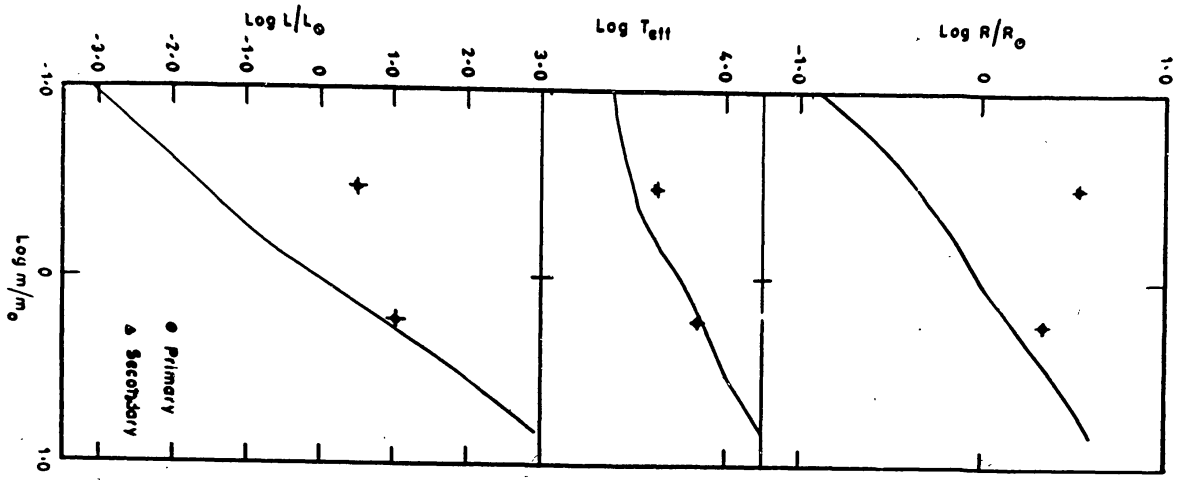

Figure 2. TW And: Positions (with error bars) of the primary (●) and secondary (▲) components in the plot of log $M/M_{\odot}$ vs Log $L/L_{\odot}$, Log T_{eff} and Log $R/R_{\odot}$. The solid lines represent a part of the respective relations for the normal main sequence stars Allen 1976).

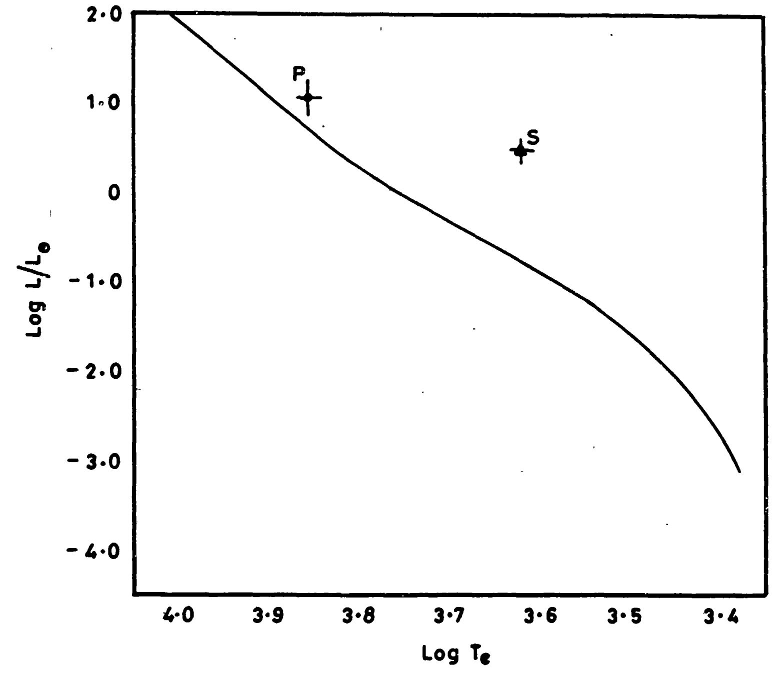

Figure 3. TW And: Positions with error bars of the primary (P) and secondary (S) components on the plot of Log T_e vs Log $L/L_{\odot}$. Solid Line represents a part of the normal HR diagram (Allen 1976).

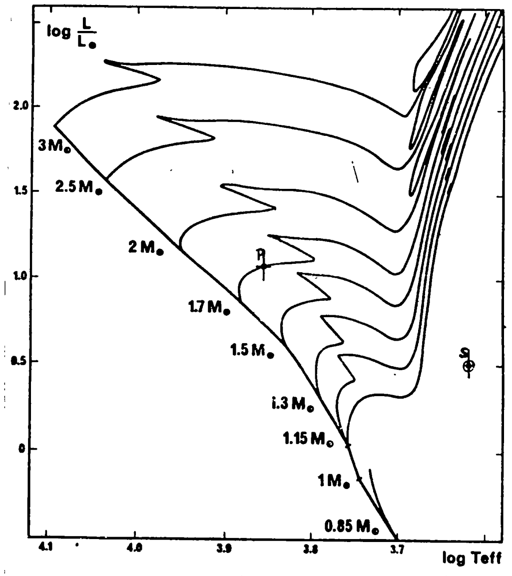

Figure 4. TW And: The location of the primary (P) and secondary (S) components (with error bars) on the plot of the evolutionary tracks of low mass stars (Maeder and Meynet 1988) of Pop I composition.

In order to understand the nature of the present status of evolution of the components of TW And, we used the evolutionary tracks computed by Maeder and Meynet(1988) for stars of Pop I composition for initial masses of $1.7M_\odot$ and $0.85M_\odot$(Fig. 4). The location of the secondary in this figure indicates that it is overluminous for its mass ($0.32\ M_\odot$)and is in a rapid expansion (subgiant) phase. The position of the primary indicates that this component is evolving along the evolutionary track of a $1.7M_\odot$ star, along which this component, with a mass of $1.68 \pm 0.07M_\odot$ was expected to evolve if it were a single star or a component of a detached binary system. However, TW And is a semidetached binary having its primary filling only 30% of its Roche lobe and the secondary filling it completely. It is well known that the secondary components in semidetached systems experience mass-loss either conservatively or non-conservatively. In both cases, the ejected matter which reaches the primary would be either accrued on its surface or an accretion disc might form around it. There are no theoretical studies that can trace the evolutionary path of the present primaries in the semidetached systems. It is clear from our studies that the evolution of the primary component in the semidetached system, TW And, is similar to that of a single star of its mass and that its evolution up to the present phase was not affected by the accrued mass, if any. In a similar study by Vivekananda Rao and Sarma(1994), the primary of TT Hya, with a mass of $2.6M_\odot$, is found to behave similar to a $2.0M_\odot$star. The studies of HU Tau by Parthasarathy et al. (1995) showed that the primary component of this system, with a mass of $4.6M_\odot$, behaves like a $3.0M_\odot$ star. This peculiar behaviour of the primary components of TT Hya and HU Tau was explained by the authors as possibly due to the primary components accruing matter only in the recent past as a result of mass transfer from Roche lobe overflow of the secondary and therefore the structure of the primary components in these systems may be different from those of single stars of similar mass. In the case of the primary of TW And, with a mass comparatively smaller than those of TT Hya and HU Tau it appears that either any mass accrued by it had no effect on its evolution or that all the matter ejected by the Roche lobe filling secondary had escaped from the system. We suggest that theoretical studies of the conditions of the mass accruing primary components in semidetached systems is important for a better understanding of the problem.

Assuming that the primary component was not affected by the accrued matter(if any) and its present position on the evolutionary track of a $1.7M_\odot$ star represents truly its own evolution, we estimated the age of the system to be $2.7 \pm 0.2 \times 10^9$ years.

5. Conclusions

From an analysis of the v and b light curves of the semidetached binary system TW And using the Wilson-Devinney method(1971) with $T_{c,h}(7200^0$ K) and q(0.193) being treated as fixed parameters, we derived its improved absolute elements. Since the evolution of the primary component, up to the present phase, does not appear to be affected by any matter accrued from the Roche lobe filling secondary component, it is suggested that theoretical studies of the physical conditions of mass accruing primary components in semidetached systems are very important.

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