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FUNDAMENTAL PHOTOMETRIC DATA FOR TWO CONTACT BINARIES: MW PAVONIS AND TY MENSAE

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ABSTRACT

The *UBV* light curves of MW Pav and TY Men were reanalyzed by means of the Wilson and Devinney method. They were found to have contact configurations. The asymmetrics in the light curves were handled as if they were caused by a hot spot. The evolutionary stage was estimated by two different methods, and in both cases the systems were found to be evolved. It is concluded that MW Pav is a classic A-type W UMa system, while TY Men is an early-type contact binary with marginal physical and thermal contact.

I. INTRODUCTION

Two presumptive contact systems of some similar characteristics in their light curves were observed in *UBV* photoelectric photometry at the Bosque Alegre Station of Cordoba Observatory. The light curves of MW Pav and TY Men were initially analyzed with the classic Russell and Merrill (1952) model, and it was found that their dimensions were roughly comparable to those of a contact configuration (Lapasset 1977, 1978).

However, it is well known that this method can be considered just a first approach to a more realistic description for close binaries. Hence, both systems are here reanalyzed by means of the Wilson and Devinney (1971) model, which is especially powerful for handling contact systems.

II. LIGHT CURVES ANALYSIS

A common fact to both binaries are the asymmetries in the primary minima and differences of height in the maxima. These features are more pronounced in TY Men light curves, and they also show some variations from epoch to epoch, as first pointed out by Naqvi and Grønbech (1976). In addition, as a consequence of the asymmetry in the primary minimum, the secondary is slightly displaced from phase $\phi = 0.50$.

The 401 observations in each color—*U, B,* and *V*—of MW Pav were grouped into 63 normal points and weighted according to the number of observations per normal point and to the typical scattering of the observations in each wavelength. The three light curves were used simultaneously in deriving the photometric solution. Two different procedures were followed in analyzing MW Pav: (1) an analysis accomplished by using the entire light curves, without modifications; (2) another analysis carried out under the assumption that a hot spot model (Naqvi and Grønbech 1976; Lapasset 1978) could explain the already-mentioned asymmetries; thus the presumed parts of the light curves affected by the hot spot (between phases $\phi = 0.00$ and 0.35) were excluded from the analysis. Although an alternative possibility would be the assumption of dark spots on the opposite hemisphere, the hot spot model was preferred because of the arguments given by Naqvi and Grønbech (1976) in their paper on TY Men. In addition, the results of MW Pav will give some validity to this hypothesis, as will be shown in Sec. III.

Exactly the same procedure was followed for TY Men; in this case, I had 340 observations in each wavelength which were grouped into 57 normal points. In addition, for case (2), phases were slightly modified in order to make the secondary minimum fall in the phase $\phi = 0.50$.

All the computations were started at a set of parameters compatible with the solutions found by the classic model. The first approaches were made by trial and error, using Wilson and Devinney's (1971) light curve program. When a solution that marginally represented the observations was obtained, the analysis proceeded with the differential corrections program. In all cases, it was necessary to group the set of adjustable parameters into subsets of not strongly correlated parameters in order to get a better fit of the observations (see Wilson and Biermann 1976). The computations were stopped when the corrections to all the adjustable parameters were reduced to values similar to or smaller than their probable errors.

The temperatures of the primary components were fixed in accordance with the observed color indexes, $B - V$ and $U - B$, of the systems, and were obtained from the tables of Morton and Adams (1968). The value I found for the effective temperature of MW Pav was 7260 K, and for TY Men, 7775 K. An empirical correction of about 5% was added to obtain the polar temperature listed in Tables I and II.

The initial values of the limb-darkening coefficients were deduced from the above established temperatures, in the grid model atmospheres of Carbon and Gingerich (1969) for $\log g = 4.0$. In the last runnings of the differ-

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TABLE I. Photometric parameters for MW Pav.

	Case (1)	Case (2)
i (°)	85.17 ± 0.74	85.07 ± 0.69
m_2/m_1	0.1826 ± 0.0029	0.1822 ± 0.0035
$\Omega_1 = \Omega_2$	2.380 ± 0.0032	2.1285 ± 0.0040
T_1 (pole)[a] (K)	7620	7620
T_2 (pole)[a] (K)	7565	7570
$g_1 = g_2$[a]	0.18 ± 0.07	0.15 ± 0.09
$A_1 = A_2$[a]	0.50 ± 0.10	0.20 ± 0.15
% overcontact	43.6	50.4
r_1 (pole)	0.5062 ± 0.0008	0.5085 ± 0.0010
r_1 (side)	0.5571 ± 0.0012	0.5606 ± 0.0015
r_1 (back)	0.5829 ± 0.0015	0.5871 ± 0.0019
r_2 (pole)	0.2410 ± 0.0010	0.2434 ± 0.0012
r_2 (side)	0.2528 ± 0.0011	0.2558 ± 0.0015
r_2 (back)	0.2998 ± 0.0025	0.3067 ± 0.0034
$L_1/(L_1 + L_2)$ V	0.8174 ± 0.0034	0.8156 ± 0.0040
$L_1/(L_1 + L_2)$ B	0.8185 ± 0.0039	0.8166 ± 0.0049
$L_1/(L_1 + L_2)$ U	0.8198 ± 0.0045	0.8178 ± 0.0058
$x_1 = x_2$[a] v	0.534 ± 0.040	0.487 ± 0.041
$x_1 = x_2$[a] B	0.554 ± 0.040	0.485 ± 0.041
$x_1 = x_2$[a] U	0.599 ± 0.041	0.543 ± 0.040

[a] Nonadjustable parameters.

TABLE II. Photometric parameters for TY Men.

	Case (1)	Case (2)
i (°)	79.69 ± 0.56	79.52 ± 0.50
m_2/m_1	0.2200 ± 0.0061	0.2150 ± 0.0029
$\Omega_1 = \Omega_2$	2.2347 ± 0.0131	2.2566 ± 0.0076
T_1 (pole)[a] (K)	8164	8164
T_2 (pole) (K)	7623 ± 121	7183 ± 63
$g_1 = g_2$[a]	0.30 ± 0.14	0.90 ± 0.09
$A_1 = A_2$[a]	1.00 ± 0.22	0.75 ± 0.15
% overcontact	33.7	9.5
r_1 (pole)	0.4908 ± 0.0031	0.4846 ± 0.0018
r_1 (side)	0.5360 ± 0.0045	0.5606 ± 0.0025
r_1 (back)	0.5627 ± 0.0056	0.5871 ± 0.0030
r_2 (pole)	0.2513 ± 0.0035	0.2434 ± 0.0019
r_2 (side)	0.2629 ± 0.0042	0.2558 ± 0.0023
r_2 (back)	0.3076 ± 0.0085	0.3067 ± 0.0040
$L_1/(L_1 + L_2)$ V	0.8289 ± 0.0061	0.8663 ± 0.0040
$L_1/(L_1 + L_2)$ B	0.8370 ± 0.0069	0.8788 ± 0.0051
$L_1/(L_1 + L_2)$ U	0.8460 ± 0.0076	0.8923 ± 0.0060
$x_1 = x_2$[a] V	0.560 ± 0.044	0.580 ± 0.035
$x_1 = x_2$[a] B	0.630 ± 0.043	0.690 ± 0.033
$x_1 = x_2$[a] U	0.580 ± 0.048	0.570 ± 0.037

[a] Nonadjustable parameters.

ential correction program, they were also adjusted to their final values showed in Tables I and II.

In all the computations for both systems, the limb-darkening coefficient x_2, the albedo A_2, the gravity-darkening exponent g_2, and the modified gravitational potential Ω_2 of the secondary component were set equal to x_1, A_1, g_1, and Ω_1, respectively. The temperature of the secondary component, T_2, was treated in a different way for each binary, as will be explained in Sec. III.

III. THE RESULTS

a) *MW Pavonis*

The observed light curves of MW Pav are displayed in Fig. 1; they show the characteristics of a W UMa system, with the secondary minimum being a total eclipse of almost the same depth as the primary minimum. Mode 1 of the Wilson and Devinney (1971) method was employed in deriving the solutions (see Leung and Wilson 1977 for a detailed description of the modes of operation). This means that the temperature of the secondary component is not a free parameter but that it is calculated from the expression $T_2 = T_1(a_2/a_1)\exp(0.25g)$, where a_1 and a_2 are gravity accelerations in the poles of both components and g is the gravity-darkening exponent.

The results are shown in Table I, while the light curves of solution (2) are presented in Fig. 1. Solution (1) gives almost the same fitting of the observations. Even though this analysis includes the normal points between phases $\phi = 0.00$ and 0.35, the resulting light curves tend to fit the two minima and the secondary maximum; the "perturbed" zone seems to be, in fact, that excluded in my second analysis. I suggest this to be an indication, not a definite one, of course, that a hot spot model is more likely than a dark spot one for this system.

A comparison of the two solutions in Table I does not show any substantial difference between the values of the main parameters.

b) *TY Mensae*

As can be seen in Fig. 2, the secondary minimum is also a total eclipse but is shallower than the primary by about 0.1 mag. This suggests a relatively large difference between the temperatures of both components. In effect, attempts to fit the observations with mode 1 failed. Hence mode 3 was employed, in which T_2 is an adjustable programmer.

The results are shown in Table II, and some definite differences between both solutions can be noticed there; i.e., T_2 is smaller by about 440 K in the "symmetric" solution, and so is the degree of overcontact that is only of 9.5% in this case.

These values can be compared to two already well studied systems: BV 845 (Leung and Darland 1978) and V1010 Oph (Leung and Wilson 1977): they both have marginal contact (4.5% and 16.6%, respectively) and they also show some asymmetries in the light curves and large differences of temperature between components. The configurations are also similar, the primary component being larger, more massive, hotter, and more luminous than the secondary.

This type of star, in which temperatures of both components are not coupled, in addition to the already mentioned asymmetries and variations in the light curves, suggests that the systems are undergoing changes in their structure, including processes of mass exchange. However, for none of these three binaries have changes in the period yet been detected.

The errors presented in Table I and II are the probable errors given by the last runnings of the differential corrections program. They are just the formal errors

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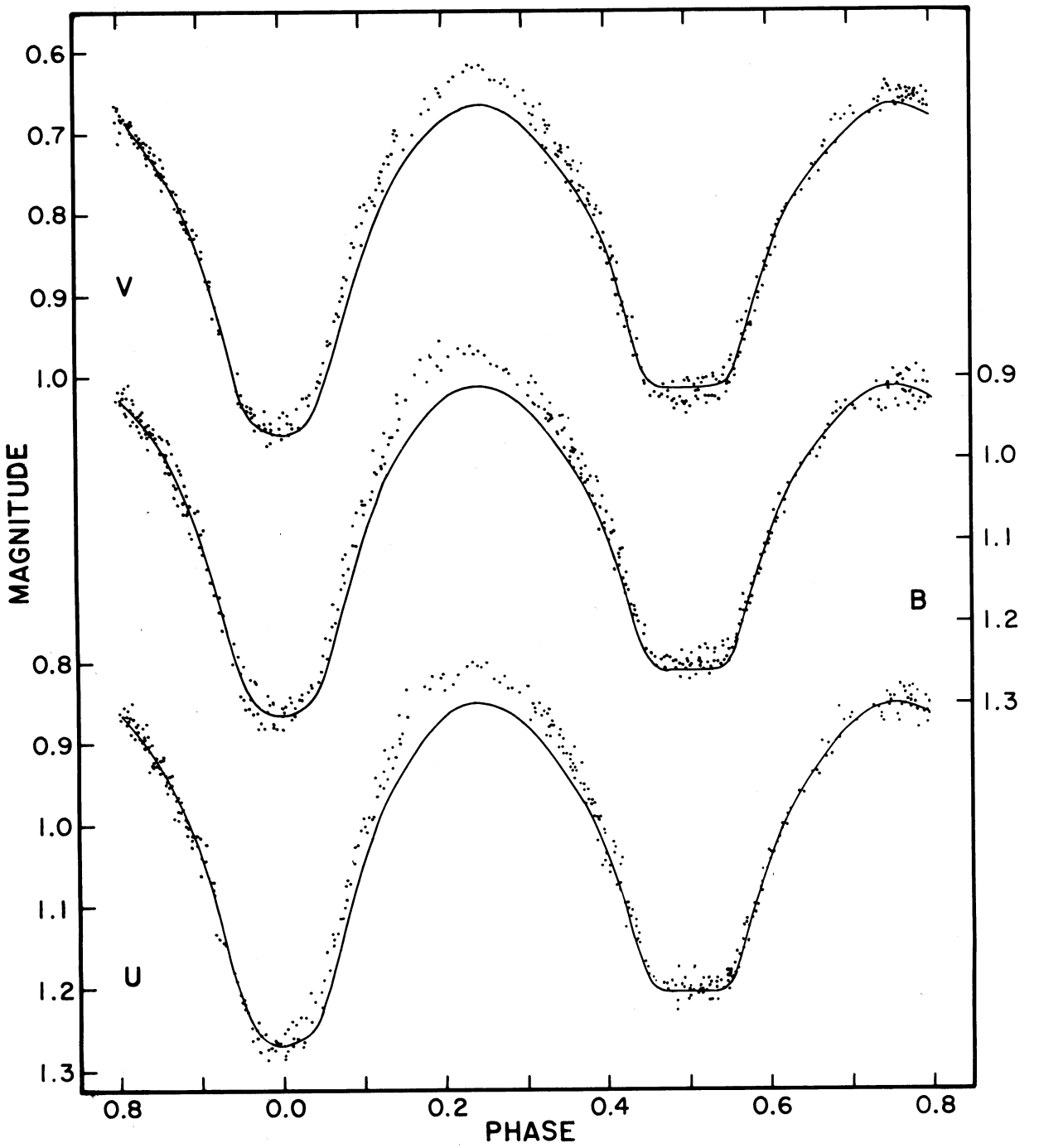

FIG. 1. *UBV* observations of MW Pav. Magnitudes are in the sense variable minus comparison star. The solid lines represent my case (2) ("symmetric") solution.

showing the internal consistency of the method, as long as an accurate interpretation of the asymmetries is still lacking for these systems.

IV. EVOLUTIONARY STATE

Since the absolute dimensions of MW Pav and TY Men are not known, we are unable to say directly whether the systems are at zero age or evolved. However, there are two ways of gaining some knowledge about the evolutionary state of contact binaries. The first one is due to Wilson (1978), and it is based in a comparison between these two expressions:

$$a_k = 4.2088 P^{2/3}(1+q)^{1/3} M_1^{1/3},$$

$$a_z = F(1+q^{0.6}) M_1^{0.6},$$

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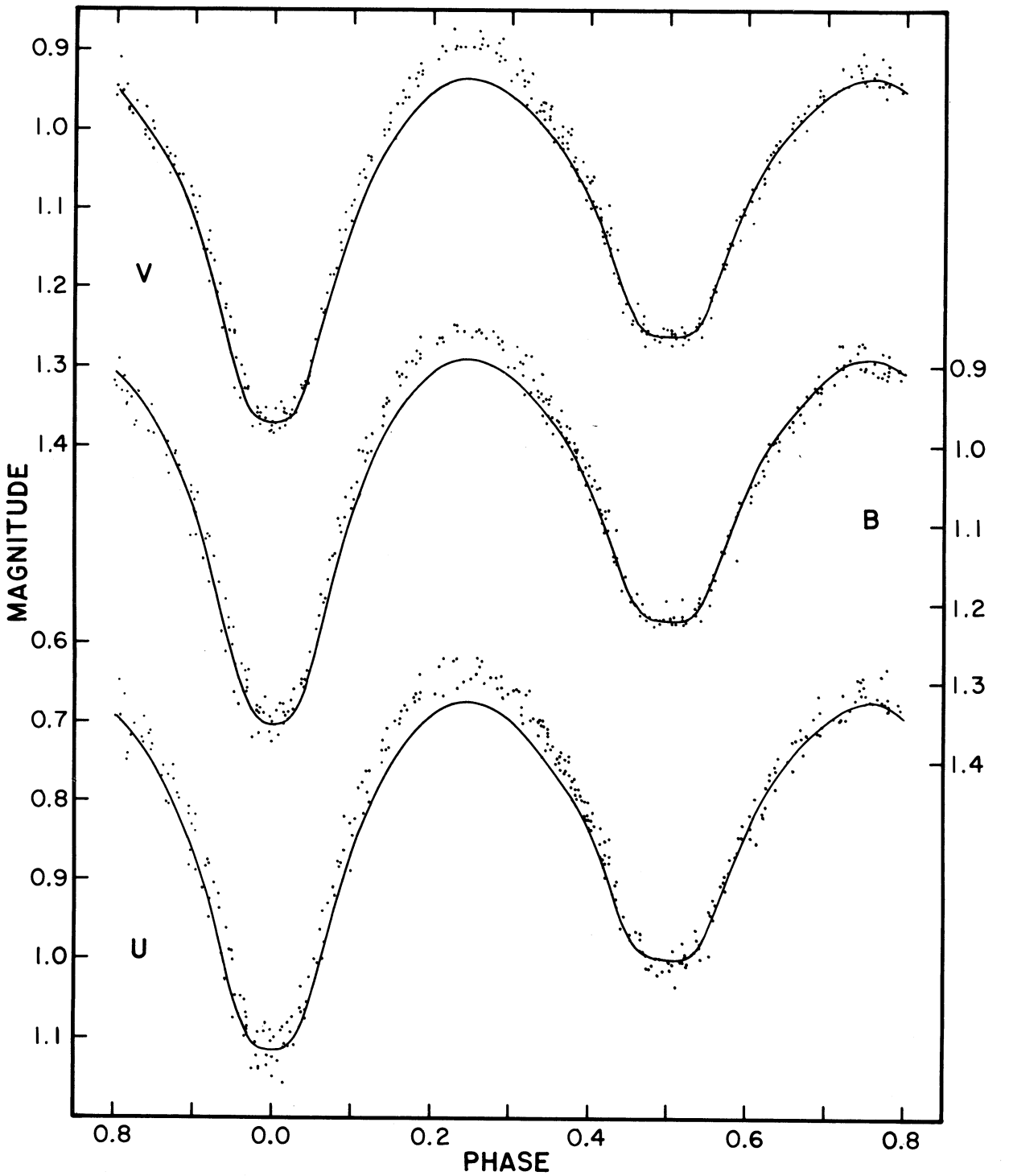

FIG. 2. *UBV* observations of TY Men. Magnitudes are in the sense variable minus comparison star. The solid lines represent my case (2) ("symmetric") solution.

where a_k is the absolute separation between components from Kepler's third law; a_z is the separation that would correspond to zero-age contact binaries, using the mass-radius relation $R = M^{0.6}$; and $F = 1/(\bar{r}_1 + \bar{r}_2)$ can be deduced from the geometry of the solutions.

Of course, some reasonable values for the primary component mass M_1 must be assumed. In Table III, I show the results for $M_1 = 1.0M_\odot$, $2.0M_\odot$, and $3.0M_\odot$, for case (2) B of my solutions [there are no major differences for case (1)]. In all cases the deduced separation a_k is bigger than that corresponding to nonevolved stars.

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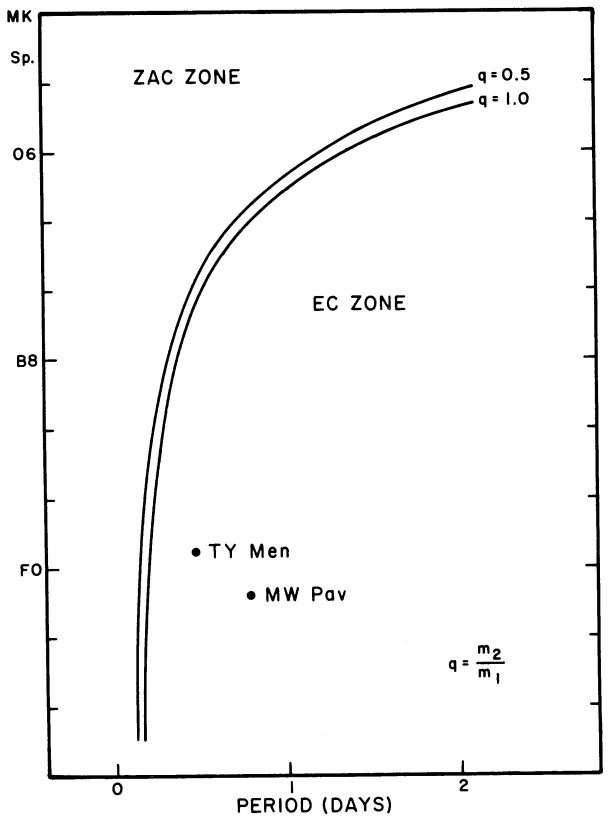

FIG. 3. Period–spectral type diagram from Leung and Schneider (1977); ZAC stands for zero-age contact, and EC for evolved contact. Solid curves represent the theoretical zero-age relation for mass ratios of 1.0 and 0.5.

In addition, following Leung and Schneider (1977), a simple indicator of the evolutionary state is the period–spectral type diagram. It is shown in Fig. 3, where the ZAMS mass-radius relation of Stothers (1972) has been used for $q = 0.5$ and 1.0. Both MW Pav and TY Men fall in the evolved contact zone.

TABLE III. Evolutionary state based on Wilson's method.

	MW Pav	TY Men
P (days)	0.794989	0.461667
$\bar{r}_1$	0.5523	0.5230
$\bar{r}_2$	0.2651	0.2612
F	1.2270	1.2752
M_1 (M_0)	1.0, 2.0, 3.0	1.0, 2.0, 3.0
a_k (R_0)	3.82, 4.87, 5.57	2.68, 3.38, 3.87
a_z (R_0)	1.67, 2.53, 3.23	1.78, 2.70, 3.45

Both estimations then yield to the same conclusion, namely these two systems are evolved from the zero-age main sequence. It should be pointed out, however, that even though these binaries have in general many points in common, and the spectral types are not too different (~F2 for MW Pav and ~A9 for TY Men, from their color indexes), they probably belong to two quite structurally different type of binaries. MW Pav seems to be a typical member of the A-type W UMa systems (see Wilson 1978); it is clearly evolved and with a definite degree of overcontact, and it is probably also in some stable phase of its evolution, holding good thermal contact between components.

TY Men (as BV 845 and V1010 Oph) should be considered an early-type contact system with marginal physical and thermal contact, not so evolved, and surely not so stable.

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