JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
38: 43 ~ 57, 2005

ABSOLUTE PARAMETERS AND MASS–RADIUS–LUMINOSITY RELATIONS FOR THE SUB–TYPES OF W UMa BINARIES

N. S. AWADALLA, AND M. A. HANNA
National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, EGYPT
e-mail: magdyamh@yahoo.com

(Received March 14, 2005; Accepted June 13, 2005)

ABSTRACT

The authors have assembled a sample of 80 W UMa binary systems (42 W–subtype and 38 A–subtype) whose light curves have all been solved by means of the recent W–D code and combined with up-to-date radial velocity solutions. The absolute parameters (masses, radii and luminosities) have been derived (without any constraint on the physical parameters). The main results of this paper are: (1) the mass–luminosity relations for both W&A–subtypes as well as for all W UMa contact binaries have been shown, (2) the mass–radius relations have been found for both subtypes, (3) some remarks on the evolution status have been presented.

Key words : contact binaries — W UMa type — parameters — catalogue — mass-radius-luminosity relation — angular momentum.

I. INTRODUCTION

The W Ursae Majoris systems are eclipsing variable binary stars whose light curves have maxima which are strongly curved and minima which are nearly equal in depth. These systems are spectroscopic double stars and the spectra usually contain absorption lines from both components. Before 1950 most light curves were observed photographically. For some time a few radial velocity curves were published but recently many radial velocity curves as well as the photoelectric and CCD light curves of these systems have been observed. Lucy (1968a, 1968b) shows that the W UMa stars are contact binaries, with a common convective envelope whose photosphere lies between the inner and outer Lagrangian zero-velocity surfaces. Several authors have made further studies on the stellar structure aspect of the W UMa problem, e.g., Hazlehurst (1970), Moss and Whelan (1970), Moss (1971), Mochnacki (1981), Kähler et al. (1986, 1987), Kähler (2002a, 2002b) and Kähler (2004). All these authors have retained the common convective envelope model's basic feature, which is the energy exchange between the components. A review of this subject have been presented by Binnendijk (1977) and Rucinski(1978). Binnendijk (1970) divided these systems into two subtypes: W–subtype shallow contact binaries where the middle of the increasing branch of its radial velocity curve occurs at phase zero while A–subtype over contact binaries where the middle of the decreasing radial velocity branch occurs at phase zero. Also, the primary minimum corresponds to transit eclipse of the larger, more massive component for the A–subtype and occultation eclipse of the smaller, less massive component for W–subtype. The effective surface temperature of the secondary in a W–subtype is higher than of the primary. The physical differences between these two subclasses are summarized and discussed by Rucinski (1973, 1974). Also, the W UMa–type contact binaries show O'Connell effect which is an obvious difference between the two maxima in their light curves (Milone, 1968).

All the above noted observational phenomena of the W UMa type binaries still present a challenge. One of the most important characteristic behavior of the W UMa binaries is its mass–luminosity relation which can shed light to understanding of the above phenomena. The relation ($L \propto M^{\alpha}$) has been studied by many investigators and for different luminosity classes (e.g., Russell and Moore, 1940; Parenago and Masevich, 1951; Kopal, 1959; Binnendijk, 1960; Harris et al., 1963; Osaki, 1965; Lucy, 1973; Dworak, 1975; Heintz, 1978; Smith, 1983; and Rovithis–Livaniou et al., 1992). They have found different values of α which range from 1.8 (Binnendijk, 1960) to 5.7 (Kopal, 1959). Rovithis–Livaniou et al. (1992) have found that $L_1/L_2 = (M_1/M_2)^{0.82}$ for W UMa binaries whose light curves have been analyzed by Wilson-Devinney (hereafter W–D) Code (Wilson & Devinney 1971), while $\alpha = 1.04$ for the systems analyzed by Kopal's method (Fourier Technique). While, Lucy (1968b, 1973) has found that $L_1/L_2 \simeq (M_1/M_2)^{0.92}$ and Osaki (1965) has found that $L_1/L_2 = M_1/M_2$. Recently, Csizmadia and Klagyivik (2004) found that there is no strict mass ratio–luminosity ratio relation for contact binary stars.

On the other hand, the mass luminosity relation has been studied for low masses based on visual binaries data (see Delfose et al., 2000; Henry et al. (1999) and Malkov et al., 1997) and based on eclipsing binaries data (e.g., Kovaleva, 2001 and Gorda & Svechnikov, 1998). Malkov (2003) has concluded that the mass–luminosity relation based on empirical data of eclipsing

---

Corresponding Author: M. A. Hanna

binary components can not be used to derive the stellar initial mass function.

The aim of this article is to study the mass–luminosity relations as well as the mass–radius relations for the W&A–subtypes of W UMa binary systems with some other statistical relations. So, firstly we have to use accurate absolute parameters (masses, radii, and luminosities) for W UMa systems. Secondly we are going to compare the present results with the previous works and to study the evolutionary status of these systems on the basis of their position in the zero age main sequence (ZAMS) and terminal age main sequence (TAMS).

II. DETERMINATION OF THE ABSOLUTE PARAMETERS

The problem of determining the absolute parameters of W UMa binaries has been discussed by various investigators using different approaching methods. The accuracy and reliability of these parameters strongly depend on both spectroscopic and photometric data. In the present study a sample of 80 W UMa type close binaries (42 of W–subtype and 38 of A– subtype) have been chosen such that: (1) they have many and high–quality photoelectric and CCD observations, (2) they have analyzed light curves by the use of W–D code and (3) for all of them the spectroscopic mass ratios (q_{sp}) are known from recent reliable radial velocity curves. Therefore, we can emphasize that all the systems selected are obtained with the same criterion analysis and are homogenous.

In order to calculate the absolute parameters of the 80 W UMa binary systems, we used the well known formulae:

$$A^3 = 74.5\,P^2\,(M_1 + M_2), \qquad (1)$$

$$R_1 = A\,r_1,\; R_2 = A\,r_2, \qquad (2)$$

$$L_1 = R_1^2 T_1^4,\; L_2 = R_2^2 T_2^4, \qquad (3)$$

where Equation (1) is the third Kepler's law, A is the separation between the two components expressed in solar radii, P is the orbital period in days, M_1 and M_2, are the masses of the components in solar mass.
Equation (2) is the relation between absolute R_1 & R_2 and relative r_1 & r_2 radii of the components. The relative radii have been taken equal to the geometric mean of the polar, side and back radii, that were computed ad hoc with W–D code when they are not provided by the original authors.
Equation (3) is the Stefan-Boltzman Law, L_1 and L_2 are integral bolometric luminosities expressed in solar units, T_1 and T_2 are the effective temperatures in units of solar effective temperature ($T_\odot = 5870\,\mathrm{K}$).

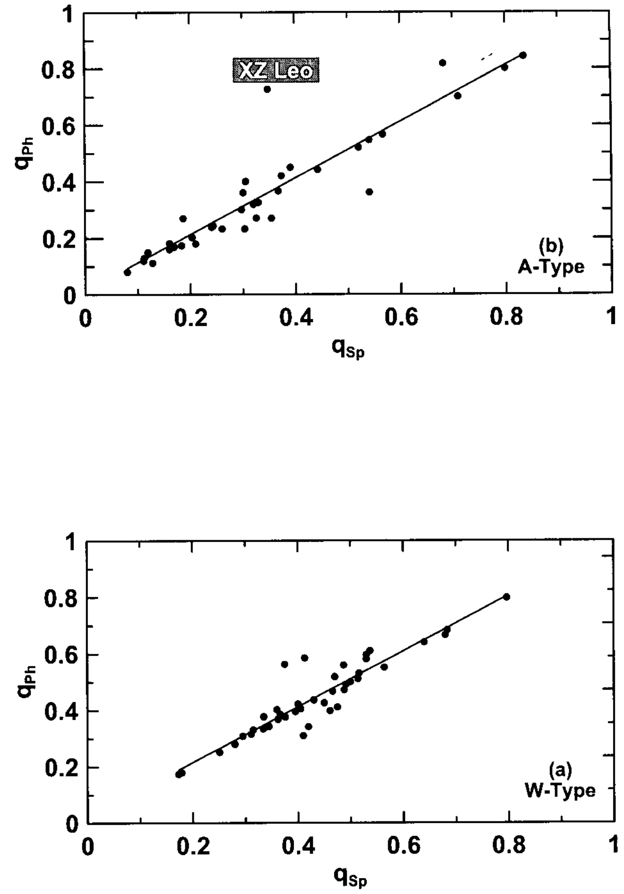

Fig. 1.— Spectroscopic versus photometric mass ratio for W&A–subtype of W UMa binaries.

Table 1 lists W&A–types in an alphabetical constellation order. The systems have the latest modern photometric and spectroscopic solutions which provide the basic observational data: period, mass ratio $q = m_2/m_1$ spectroscopically (sp) and photometrically (ph), the inclination i, $(M_1 + M_2)\ \sin^3 i$ and the geometrical mean radii r_1 & r_2.

The column "class" of Table 1 should serve as a reference to judge the quality of the spectroscopic orbit (first letter) and of the photometric analysis (second letter). The former is taken from the Batten et al. (1989) "Eighth Catalogue of the Orbital Elements of Spectroscopic Binary Systems" a classification in five classes of decreasing quality from A to E. The judgment about the quality of photometric solution is similarly based on four classes of decreasing quality, equivalent to good-fair-poor-very poor. The judgement is necessarily subjective, but it is based on a number of checks (quality of photometry, deviation between computed and observed curves, existence of recent spectroscopic data, version of the W–D code and applied method of solution). The aim of this rough classification is just to keep somehow the memory of the original data quality.

The last column in Table 1 lists references. The first number is for the radial velocity solution, while the second for the photometric light curve analysis of the system.

Table 1.
Light and radial velocity curve elements for W UMa systems

a) W–type									
Name	Period	q_{sp}	q_{ph}	i	$M_t \sin^3 i$	r_1	r_2	cl.	Ref.
AB And	0.3318911	0.491	0.491	86.80	1.490	0.45	0.33	E,A	1,8
GZ And	0.3050184	0.514	0.511	85.86	1.763	0.45	0.45	A,A	22,49
V417 Aql	0.3703117	0.362	0.368	84.47	1.874	0.48	0.31	A,A	22,42
SS Ari	0.4059836	0.295	0.308	74.60	1.501	0.49	0.29	C,A	20,15
44i Boo	0.2678192	0.487	0.559	72.80	1.132	0.42	0.32	C,C	23,6
AC Boo	0.3524411	0.410	0.310	82.60	1.960	0.50	0.22	C,C	9,43
TY Boo	0.3171505	0.466	0.466	77.50	1.637	0.45	0.32	A	30,30
AO Cam	0.3299035	0.413	0.585	75.10	1.520	0.44	0.34	A,C	37,2
BH Cas	0.4058916	0.475	0.411	71.66	0.910	0.47	0.32	B,B	29,52
V523 Cas	0.2336923	0.516	0.530	83.67	1.110	0.42	0.31	B,D	38,19
V757 Cen	0.3431692	0.684	0.684	69.30	1.423	0.43	0.36	C,E	1,25
V752 Cen	0.3702248	0.311	0.315	81.70	1.650	0.49	0.29	C,D	2,18
VW Cep	0.2783115	0.395	0.395	63.60	1.280	0.56	0.18	E,C	1,10
TW Cet	0.3168512	0.530	0.581	83.25	1.948	0.43	0.33	B.E	1,39
AH Cnc	0.3604433	0.537	0.610	62.94	0.915	0.55	0.37	C,E	1,25
TX Cnc	0.3828822	0.530	0.596	62.40	0.860	0.43	0.33	C,D	1,28
CC Com	0.2206859	0.470	0.518	87.90	1.014	0.45	0.33	B,D	1,24
RW Com	0.2373450	0.345	0.343	75.20	0.691	0.49	0.30	C,D	1,31
RZ Com	0.3385077	0.430	0.436	86.00	1.569	0.46	0.31	A,D	1,47
LS Del	0.3638405	0.375	0.562	48.50	0.617	0.43	0.33	A,D	22,44
RW Dor	0.2854638	0.680	0.666	76.25	0.987	0.44	0.34	B,B	12,27
BV Dra	0.3500666	0.402	0.411	76.30	1.274	0.47	0.32	A,C	1,14
BW Dra	0.2921660	0.280	0.280	74.40	1.011	0.50	0.28	A,C	1,14
FU Dra	0.3067168	0.251	0.251	78.60	1.379	0.51	0.28	A,A	37,45
YY Eri	0.3215000	0.400	0.422	81.80	2.007	0.46	0.32	A,D	1,48
QW Gem	0.3581270	0.334	0.334	80.45	1.685	0.49	0.36	A,A	38,17
V728 Her	0.4712897	0.179	0.179	69.20	1.592	0.56	0.28	C,C	32,40
SW Lac	0.3207151	0.797	0.797	80.60	1.738	0.42	0.39	B,D	51,34
AM Leo	0.3657974	0.450	0.426	87.00	2.000	0.46	0.36	B,C	9, 3
XY Leo	0.2840976	0.500	0.500	65.80	1.046	0.44	0.32	A,C	1,7
RT LMi	0.3749178	0.366	0.385	84.00	1.749	0.48	0.32	A,C	37,33
V502 Oph	0.4533870	0.335	0.377	71.30	1.679	0.48	0.30	D,C	36,24
ER Ori	0.4233997	0.640	0.639	86.30	2.503	0.44	0.32	A,A	5,16
U Peg	0.3747772	0.315	0.331	76.00	1.322	0.49	0.30	A,C	1,50
BB Peg	0.3615025	0.360	0.402	79.90	1.862	0.48	0.31	A,C	22,4
BX Peg	0.2804180	0.376	0.376	87.50	1.409	0.48	0.31	C,C	41,13
AE Phe	0.3623727	0.461	0.398	89.00	1.975	0.47	0.31	A,E	1,26
OU Ser	0.2967645	0.173	0.173	74.30	0.640	0.55	0.25	A,A	37,35
V781 Tau	0.3449085	0.405	0.405	65.40	1.211	0.48	0.32	B.B	21,21
W UMa	0.3336355	0.488	0.471	82.90	1.653	0.47	0.34	C,C	1,11
AA UMa	0.4681260	0.564	0.551	80.30	1.906	0.43	0.35	A,C	46,2
AH Vir	0.4075276	0.420	0.342	86.50	1.889	0.49	0.30	C,D	1,13

TABLE 1.(CONT.)

B) A–TYPE									
NAME	PERIOD	q_{sp}	q_{ph}	i	$M_t \sin^3 i$	r_1	r_2	CL.	REF.
CN And	0.46279111	0.390	0.450	70.30	1.458	0.48	0.34	A,D	36,31
QX And	0.41181650	0.203	0.203	58.60	1.420	0.53	0.26	B	24,24
OO Aql	0.50679100	0.835	0.843	90.00	1.918	0.42	0.39	A	9,9
V535 Ara	0.62930107	0.300	0.361	82.10	1.962	0.47	0.29	C,E	2,16
AH Aur	0.49410830	0.169	0.169	75.50	1.787	0.56	0.27	A,A	34,40
XY Boo	0.37056752	0.160	0.182	69.00	0.879	0.56	0.25	C,E	2,43
CK Boo	0.35515697	0.111	0.120	65.00	1.171	0.45	0.33	A,A	34,13
RR Cen	0.60569200	0.210	0.180	78.70	2.115	0.56	0.25	B,C	2,39
Eps CrA	0.59144070	0.128	0.112	72.30	1.677	0.60	0.21	B,D	5,39
YY CrB	0.37656500	0.243	0.243	77.30	1.647	0.54	0.30	A,A	36,30
W Crv	0.38808083	0.682	0.817	88.00	1.680	0.42	0.38	A,C	35,20
DK Cyg	0.47069316	0.325	0.271	80.30	2.243	0.53	0.29	A,D	34,39
V1073 Cyg	0.78585070	0.320	0.320	68.40	1.589	0.48	0.29	D,B	2,25
V2150 Cyg	0.59186090	0.802	-	43.40	1.376	0.43	0.38	A,A	19,14
EF Dra	0.42402570	0.160	0.160	78.10	1.970	0.56	0.26	A,A	18,29
UX Eri	0.44528714	0.373	0.420	79.00	1.798	0.45	0.22	A,D	36,23
BL Eri	0.41691659	0.540	0.546	89.80	0.938	0.44	0.34	C	17,17
AK Her	0.42152272	0.260	0.233	80.80	2.364	0.52	0.26	B,D	2,20
V899 Her	0.42112200	0.566	0.566	68.70	2.331	0.45	0.35	A,A	19,27
FG Hya	0.32782780	0.112	0.129	86.80	1.567	0.59	0.29	A,A	18,44
AP Leo	0.43035477	0.297	0.301	79.90	1.774	0.51	0.28	A,A	18,14
UZ Leo	0.61805250	0.303	0.233	79.70	2.573	0.48	0.20	A,A	34,41
XZ Leo	0.48773748	0.348	0.726	73.30	2.242	0.42	0.36	A,C	34,26
UV Lyn	0.41498460	0.367	0.367	66.80	1.440	0.48	0.31	A,A	18,40
TV Mus	0.44568157	0.119	0.150	78.90	1.400	0.59	0.27	D	7,7
V508 Oph	0.34479261	0.520	0.520	86.10	1.509	0.44	0.34	B,C	2,15
V566 Oph	0.40965107	0.240	0.239	79.80	1.743	0.53	0.27	A,D	2,39
V839 Oph	0.40900560	0.305	0.400	77.00	2.032	0.49	0.33	A,B	34,1
V2388 Oph	0.80229800	0.186	0.27	83.90	1.926	0.52	0.30	A,B	38,33
VZ Psc	0.26125918	0.800	0.800	47.00	0.602	0.39	0.38	B,C	11,22
TY Pup	0.81924160	0.329	0.326	67.80	0.655	0.52	0.31	D,E	2,21
AU Ser	0.38649530	0.710	0.700	80.60	1.510	0.41	0.37	C,D	10,12
Y Sex	0.41981630	0.183	0.174	76.80	0.747	0.56	0.28	B,E	2,8
RZ Tau	0.41567630	0.540	0.362	82.70	2.458	0.50	0.33	B,E	2,4
EQ Tau	0.34134690	0.442	0.442	86.60	1.749	0.46	0.32	A,A	37,30
AQ Tuc	0.59487655	0.354	0.270	75.90	2.389	0.49	0.32	C,C	6,3
AW UMa	0.43872590	0.080	0.080	78.30	1.815	0.56	0.19	B,C	32,28
HT Vir	0.40767210	0.812	-	90.00	2.285	0.41	0.41	A,D	19,42

Table 2.
Absolute Parameters for W UMa binary systems

a) W–type

Name	A	M_1	M_2	R_1	R_2	T_1	T_2	L_1	L_2	$J(\times 10^{52})$
AB And	2.307	1.004	0.493	1.041	0.755	4540	5821	0.844	0.578	0.303
GZ And	2.309	1.176	0.601	1.032	1.032	5021	5260	0.598	0.721	0.365
V417 Aql	2.688	1.389	0.511	1.290	0.825	6030	6256	1.944	0.922	0.370
SS Ari	2.740	1.281	0.394	1.351	0.795	6135	5860	2.284	0.658	0.301
44i Boo	1.907	0.833	0.466	0.795	0.601	5300	5035	0.441	0.205	0.249
AC Boo	2.649	1.534	0.476	1.314	0.572	5530	5520	1.427	0.269	0.357
TY Boo	2.362	1.200	0.559	1.072	0.761	5469	5834	0.909	0.592	0.354
AO Cam	2.390	1.063	0.622	1.042	0.817	5533	5206	0.899	0.434	0.366
BH Cas	2.355	0.754	0.310	1.114	0.751	5550	6000	1.040	0.646	0.203
V523 Cas	1.663	0.739	0.392	0.695	0.522	4434	4720	0.165	0.120	0.199
V757 Cen	2.480	1.032	0.706	1.054	0.880	6000	5927	1.272	0.845	0.398
V752 Cen	2.591	1.295	0.408	1.280	0.754	6221	5955	2.168	0.632	0.301
VW Cep	2.174	1.277	0.504	1.209	0.398	5271	5382	0.997	0.117	0.322
TW Cet	2.459	1.258	0.731	1.048	0.819	5470	5600	0.868	0.583	0.438
AH Cnc	2.323	0.805	0.491	1.266	0.860	6416	6500	2.401	1.166	0.280
TX Cnc	2.381	0.774	0.461	1.019	0.793	6338	6400	1.481	0.932	0.269
CC Com	1.545	0.669	0.347	0.694	0.507	4302	4500	0.146	0.093	0.171
RW Com	1.475	0.569	0.195	0.717	0.441	5078	5400	0.302	0.146	0.107
RZ Com	2.381	1.101	0.480	1.088	0.728	5500	5564	0.957	0.449	0.311
LS Del	2.438	0.940	0.528	1.046	0.800	5704	5780	1.023	0.630	0.319
RW Dor	1.870	0.646	0.431	0.823	0.636	5200	4765	0.437	0.184	0.213
BV Dra	2.332	0.985	0.405	1.101	0.742	6245	6345	1.629	0.788	0.264
BW Dra	1.931	0.884	0.248	0.963	0.542	5980	6164	1.049	0.375	0.162
FU Dra	2.173	1.170	0.294	1.117	0.606	5800	6133	1.247	0.460	0.299
YY Eri	2.517	1.456	0.614	1.153	0.793	5600	5317	1.155	0.444	0.414
QW Gem	2.561	1.317	0.440	1.242	0.924	6100	5890	1.888	0.909	0.318
V728 Her	3.183	1.653	0.296	1.789	0.898	6622	6776	5.437	1.501	0.270
SW Lac	2.403	1.007	0.803	0.997	0.925	6200	5834	1.298	0.876	0.418
AM Leo	2.715	1.408	0.600	1.260	0.983	6200	6380	2.073	1.415	0.418
XY Leo	2.024	0.919	0.459	0.899	0.654	4575	4850	0.313	0.209	0.263
RT LMi	2.650	1.284	0.494	1.272	0.838	5855	6000	1.681	0.803	0.351
V502 Oph	3.116	1.435	0.541	1.493	0.935	5968	6200	2.497	1.141	0.418
ER Ori	3.228	1.535	0.983	1.130	1.388	5650	5800	1.149	1.926	0.650
U Peg	2.474	1.087	0.360	1.207	0.735	5860	5841	1.519	0.555	0.257
BB Peg	2.668	1.392	0.560	1.286	0.833	6200	5883	2.160	0.734	0.393
BX Peg	2.023	1.027	0.386	0.965	0.617	5300	5528	0.649	0.314	0.241
AE Phe	2.684	1.413	0.563	1.269	0.843	5871	6100	1.692	0.869	0.398
OU Ser	1.676	0.622	0.106	0.918	0.426	5960	6380	0.940	0.265	0.070
V781 Tau	2.426	1.147	0.464	1.155	0.776	5861	5950	1.391	0.667	0.311
W UMa	2.412	1.150	0.542	1.126	0.813	5800	6194	1.269	0.859	0.345
AA UMa	3.191	1.283	0.707	1.356	1.101	5965	5929	2.058	1.323	0.491
AH Vir	2.864	1.416	0.484	1.401	0.871	5400	5783	1.474	0.749	0.368

TABLE 2. (CONT.)

B) A–TYPE										
NAME	A	M_1	M_2	R_1	R_2	T_1	T_2	L_1	L_2	$J(\times 10^{52})$
CN And	3.032	1.205	0.542	1.449	1.031	6200	4680	2.743	0.451	0.393
QX And	3.067	1.898	0.385	1.632	0.804	6500	6421	4.200	0.970	0.339
OO Aql	3.323	1.041	0.877	1.382	1.283	5700	5635	1.783	1.466	0.524
V535 Ara	3.905	1.483	0.536	1.847	1.121	8750	8572	17.676	5.994	0.469
AH Aur	3.296	1.685	0.285	1.856	0.897	6215	6141	4.541	1.010	0.267
XY Boo	2.227	0.914	0.166	1.245	0.566	7200	7102	3.682	0.720	0.127
CK Boo	2.454	1.404	0.169	1.097	0.815	6400	5685	1.784	0.613	0.142
RR Cen	3.943	1.901	0.342	2.188	0.974	7250	7188	11.692	2.238	0.347
Eps CrA	3.697	1.744	0.195	2.200	0.788	7100	6639	10.868	1.065	0.204
YY CrB	2.656	1.427	0.347	1.426	0.805	6135	6142	2.546	0.814	0.274
W Crv	2.663	0.926	0.757	1.121	1.017	5600	4937	0.092	0.543	0.410
DK Cyg	3.381	1.843	0.499	1.789	0.987	7351	7200	8.255	2.315	0.436
V1073 Cyg	4.497	1.498	0.479	2.154	1.318	6700	6661	8.263	3.020	0.465
V2150 Cyg	4.803	2.355	1.889	2.075	1.820	8000	7920	15.580	11.519	1.386
EF Dra	3.043	1.813	0.290	1.704	0.779	6000	6054	3.325	0.720	0.263
UX Eri	3.039	1.339	0.562	1.362	0.678	5900	5710	1.985	0.432	0.417
BL Eri	2.299	0.607	0.331	1.021	0.777	5980	5603	1.177	0.526	0.196
AK Her	3.192	1.993	0.464	1.657	0.820	6400	6033	4.070	0.788	0.406
V899 Her	3.364	1.840	1.042	1.504	1.171	5700	2677	2.110	0.062	0.736
FG Hya	2.327	1.394	0.180	1.371	0.670	5900	5852	2.012	0.466	0.147
AP Leo	2.949	1.429	0.430	1.507	0.838	6150	6250	2.871	0.946	0.343
UZ Leo	4.253	2.192	0.511	2.024	0.851	7250	7574	10.003	2.103	0.515
XZ Leo	3.563	1.893	0.659	1.482	1.283	7850	7147	7.370	3.793	0.557
UV Lyn	2.876	1.357	0.498	1.387	0.889	6045	6262	2.269	1.074	0.373
TV Mus	2.799	1.288	0.193	1.643	0.742	5980	6088	3.050	0.668	0.170
V508 Oph	2.379	1.000	0.519	1.049	0.811	6000	5830	1.260	0.672	0.318
V566 Oph	2.838	1.476	0.353	1.515	0.769	6700	6618	4.090	1.003	0.289
V839 Oph	3.014	1.569	0.628	1.462	0.989	6250	5391	2.881	0.729	0.470
V2388 Oph	4.546	1.542	0.416	2.373	1.368	6450	130	8.612	2.336	0.422
VZ Psc	1.985	0.855	0.684	0.776	0.746	4500	4352	0.218	0.177	0.323
TY Pup	3.456	0.622	0.203	1.787	1.082	7800	7658	10.440	3.555	0.172
AU Ser	2.596	0.925	0.648	1.051	0.950	5100	4780	0.661	0.417	0.370
Y Sex	2.199	0.690	0.120	1.240	0.620	7030	70	3.319	0.709	0.091
RZ Tau	3.189	1.849	0.669	1.594	1.055	7300	7098	6.379	2.499	0.530
EQ Tau	2.481	1.219	0.539	1.139	0.786	5860	5851	1.351	0.640	0.355
AQ Tuc	4.102	2.062	0.557	2.027	1.296	6900	7048	8.226	3.664	0.536
AW UMa	3.026	1.790	0.143	1.692	0.560	7175	7022	6.703	0.673	0.140
HT Vir	3.047	1.261	1.024	1.262	1.252	6100	6080	1.947	1.894	0.595

At first, before calculating the absolute parameters, a suitable mass ratio is needed. Figure 1 a, b shows the relation between spectroscopic and photometric mass ratios for W&A–subtypes of the contact binaries. In A–type the two systems CK Boo and XZ Leo show large differences between the photometric and spectroscopic mass ratios. This could be partly caused by the unreliability of the photometric mass ratio for the partially eclipsing systems, possibly third light reducing minima depths or low–quality photographic spectroscopy. Maceroni et al. (1985) indicated that the photometric mass ratios are more reliable than spectroscopic ones for totally eclipsing systems, and are sufficiently reliable for partially eclipsing systems.

A least square method has been applied to show the relation between the spectroscopic and photometric mass ratios for both subtypes W&A of W UMa binaries. Figure 1 shows a systematic trend between spectroscopic and photometric mass ratios with the following results:
For W–subtype,

$$q_{sp} = 0.02 + 0.98\ q_{ph}, \qquad (4)$$

with correlation coefficient $r_W = 0.925$ and standard deviation $s_W = 0.052$. While, for A–subtype,

$$q_{sp} = 0.05 + 0.93\ q_{ph}, \qquad (5)$$

with $r_A = 0.87$ and $s_A = 0.11$.

From the above, the photometric mass ratio (q_{ph}) has been used in computation of the absolute parameters for the systems. Only two systems, V2150 Cyg and HT Vir, q_{sp} have been used instead of q_{ph} which is not available in the literature. In case of XZ Leo the spectroscopic mass ratio has been used since it is more reasonable.

Also, Figure 2 shows a strong correlation between the relative radii ratio $k = r_2/r_1$ and q_{ph} values for both W& A–subtype contact binaries. The best fit to the data yields that:
For W–subtype;

$$k = 0.38 + 0.69\ q_{ph}, \qquad (6)$$

with $r_W = 0.76$ and $s_W = 0.08$ and for A–subtype;

$$k = 0.34 + 0.75\ q_{ph}, \qquad (7)$$

with $r_A = 0.96$ and $s_A = 0.05$.

We notice that the correlation of k and q is stronger in A–subtype than in W–subtype, while the correlations between q_{sp} and q_{ph} for both subtypes are nearly equal. This is because A–subtype usually have earlier spectral types with smaller mass ratios than W–subtype. Selam and Demircan (1994) found, for the first time, that k and q values are strongly correlated for contact and near contact binary systems with a quadratic fit, for their data, that $k = -0.37\,q^2 + 1.07q + 0.28$ with $\sum(O-C)^2 = 0.07$.

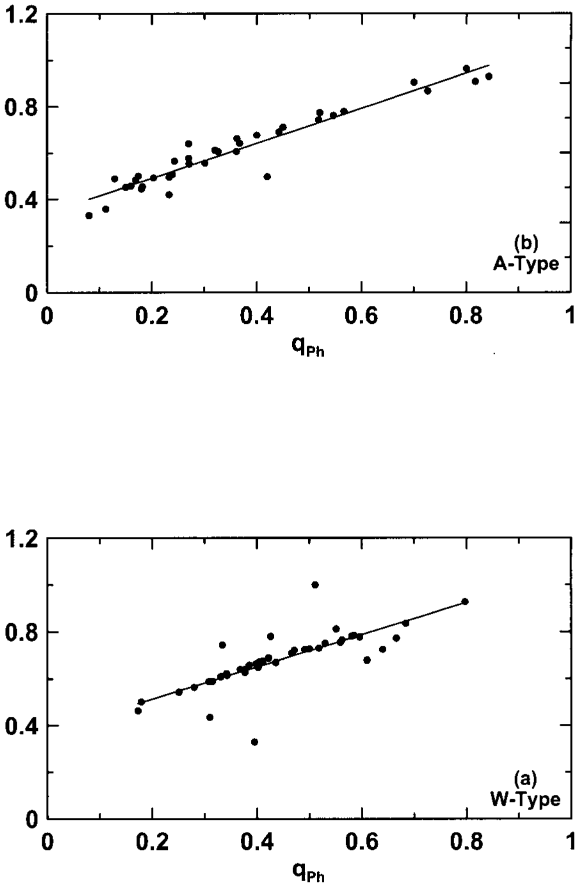

Fig. 2.— Photometric mass ratio versus radii ratio for W&A–subtype of W UMa binaries.

By the use of spectroscopic and photometric data listed in Table 1 and equations from 1 to 3, the absolute parameters of the systems were evaluated and presented in Table 2. The successive columns give the star's name, the separation (A) between the components, the individual masses, M_1&M_2, the absolute radii R_1&R_2, the luminosities L_1&L_2, the effective temperature T_1&T_2, and the total angular momentum J.

III. MASS–LUMINOSITY RELATION

The mass–luminosity diagram (Figure 3) has been constructed in the view of two main hypothesis: (i) the common convective envelop model for the W UMa binary systems (Lucy, 1968 a,b) and, (ii) the conservation of mass and angular momentum for the system. The diagrams have been shown in Figure 3 a, b and c for all systems (W&A) and for W&A–subtype separately of W UMa binaries by using the data listed in Table 2. The diagrams show the relation between $\log M_{total} = \log(M_1 + M_2)$ and $\log L_{total} = \log(L_1 + L_2)$.

Many authors have illustrated the mass–luminosity relation for W UMa binaries between the mass ratios

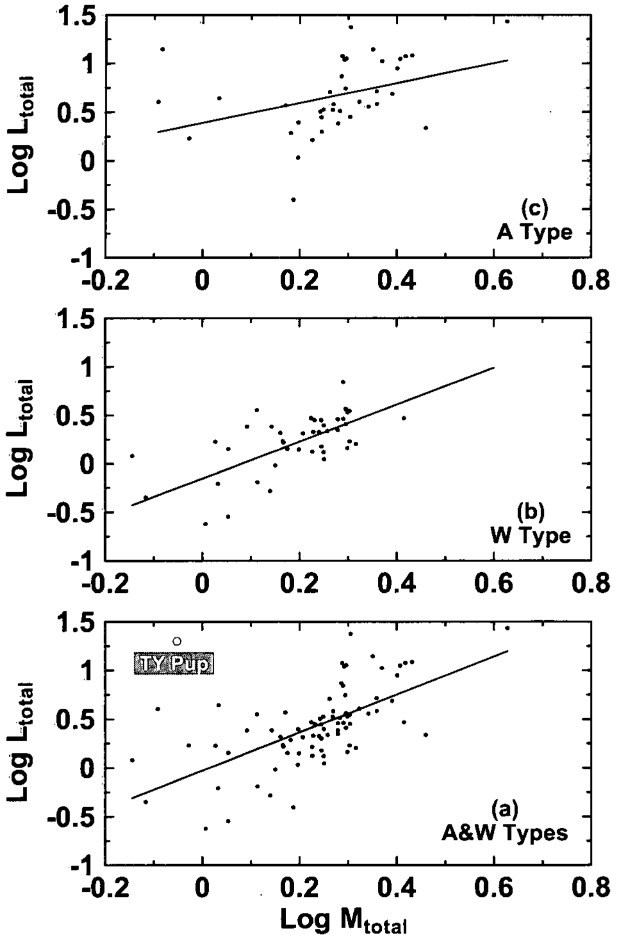

Fig. 3.— The mass–luminosity relation: (a) for all W UMa binaries (b) for W–subtype, and (c) for A–subtype contact binaries.

and luminosity ratios (cf., Osaki, 1965; Lucy, 1973 and Rovithis–Livaniou et al., 1992). In the present work, the mass–luminosity relation has been illustrated between the total mass and total luminosity to avoid the following factors: (i) the effect of mass transfer between the components. (ii) the O'Connell effect (the magnitude difference between the two maxima in the light curves of certain eclipsing systems; Milone, 1968), and (iii) any anomalous behavior in the masses or luminosities of the systems due to the light effect of third body or magnetic activity. So the global properties of the system, i.e. combined luminosity and total mass, remain unchanged.

A linear least square fitting has been applied to the data listed in Table 2. The results are as follow:

1. For all W&A– subtypes, except TY Pup due to its low quality data (see Table 1 column class);

$$\log L_{total} = -0.04 + 2.04 \log M_{total}, \tag{8}$$

with $r_{W,A} = 0.65$ and $s_{W,A} = 0.31$,

2. For W–subtype, figure 3b,

$$\log L_{total} = -0.08 + 1.6 \log M_{total}, \tag{9}$$

with $r_W = 0.62$ and $s_W = 0.24$.

3. For A–subtype, figure 3c,

$$\log L_{total} = 0.34 + 1.01 \log M_{total}, \tag{10}$$

with $r_A = 0.38$ and $s_A = 0.36$.

The mass range for the W–subtype sample, is $0.675 < M_{total} < 2.668$, while for A–subtype it is $0.727 < M_{total} < 4.244$. The correlation coefficient for all W UMa binary systems and W–subtype are reasonable, while the correlation coefficient for A–subtype binaries is poor. This is may be should serve due to the big difference of luminosity values between the different systems of the A-subtype binaries. Also these luminosities are higher than those of the W–subtype ones.

Smith (1983) found the mass–luminosity relation for 126 main–sequence stars, most of them (97) were eclipsing binaries (Popper's data, 1980) but W UMa binaries were not included. His results have been found as:

$$\log L = 3.99 \log M \quad \text{for } M > 0.43$$

and,

$$\log L = 2.26 \log M \quad \text{for } M < 0.43.$$

Most of the previous studies have introduced the relations between parameters of both components either empirically or theoretically as a logarithmic mass and luminosity ratios using small amount of data. To compar our present work with the others, we have to construct the relation using the same method. Figure 4 a, b and c represents the logarithmic mass ratio vs logarithmic luminosity ratio with the linear fit for W UMa data listed in Table 2. The results have been found as follow:

For all W UMa (A&W–subtypes) contact binaries;

$$\log L_2/L_1 = -0.10 + 0.74 \log M_2/M_1, \tag{11}$$

with $r_{W,A} = 0.64$ and $s_{W,A} = 0.20$. For W–subtype;

$$\log L_2/L_1 = -0.052 + 0.724 \log M_2/M_1, \tag{12}$$

with $r_W = 0.59$ and $s_W = 0.14$. For A–subtype;

$$\log L_2/L_1 = 0.21 + 0.65 \log M_2/M_1, \tag{13}$$

with $r_A = 0.60$ and $s_A = 0.23$.

If we consider the relation in its general form as $L \propto M^{\alpha}$, then Table 3 represents the comparison of

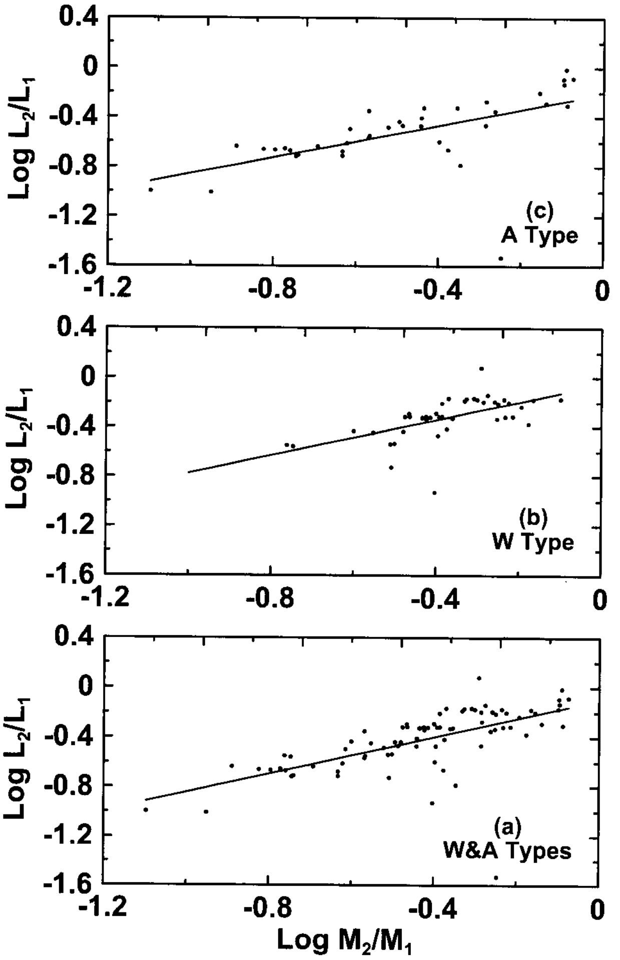

Fig. 4.— The mass-luminosity ratio relations: (a) for all W UMa binaries (b) for W–subtype, and (c) for A–subtype contact binaries.

α–values between the present work and the previous studies. Our values of α(=0.74) for all W UMa binaries could be compared with α–value (=0.82) of Rovithis–Livanou (1992) because both values were found from the same criteria analysis (W–D code) of light curves (see notice of Table 3). The difference in the α–values shown in the table could be due to the data samples used. Our data sample for W UMa binaries is more recent, big and homogenous. As far as we know, α–values for the two subtypes W&A of the W UMa binaries have not been deduced by others.

IV. MASS–RADIUS RELATION

The relation between mass and radius for each component of the contact system for both subtypes W&A has been shown in Figure 5 a, b, c and d using the data from Table 2. The linear least square fit has been applied and the following results have been obtained:

1. The mass-radius relation for the primary component

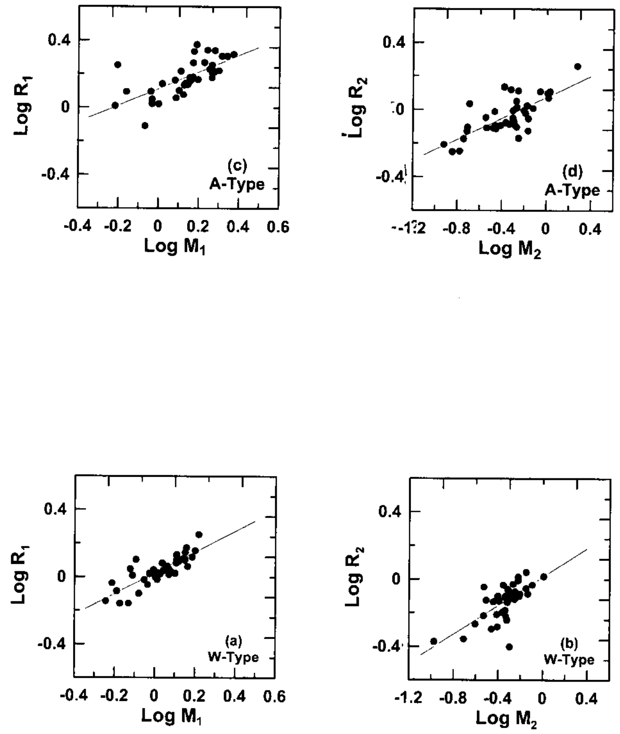

Fig. 5.— The mass–radius relations for W&A–Types for primary and secondary of W UMa binaries.

of W–subtype contact binaries was,

$$\log R_{1W} = 0.02 + 0.62 \log M_{1W}, \qquad (14)$$

with $r_{1W} = 0.84$ and $s_{1W} = 0.05$, and for the secondary components (without VW Cep):

$$\log R_{2W} = 0.02 + 0.44 \log M_{2W}, \qquad (15)$$

with $r_{2W} = 0.77$ and $s_{2W} = 0.06$.

2. The mass–radius relation for the primary components of A–subtype was (without TY Pup):

$$\log R_{1A} = 0.09 + 0.62 \log M_{1A}, \qquad (16)$$

with $r_{1A} = 0.79$ and $s_{1A} = 0.07$, and for its secondary components;

$$\log R_{2A} = 0.07 + 0.31 \log M_{2A}, \qquad (17)$$

with $r_{2A} = 0.73$ and $s_{2A} = 0.08$.

The mass range in these relations are the same as the previous mass range of the mass–luminosity relation. Maceroni et al. (1985) studied the mass–radius relations, for $M > 1.3\,M_\odot$ of the W UMa systems from different sources (Copeland et al., 1970; Lacy, 1977; Kopal, 1978; Wilson, 1978; Mengel et al., 1979 and Habets & Heintze, 1981) and found a great variety of shapes with slopes varying from 0.6 to 1.0.

From the previous results of the mass–radius relation we notice the following:

TABLE 3.
COMPARISON BETWEEN LUMINOSITY RATIO–MASS RATIO RELATION OF THE PRESENT WORK WITH THE PREVIOUS AUTHORS'S RESULTS FOR W UMA BINARIES

α–VALUES	REFERENCES
1	OSAKI (1965)
0.92	COPELAND ET AL. (1970) †
0.92	LUCY (1973) †
0.93	MENGEL ET AL. (1979) †
0.95	MENGEL ET AL. (1979) †
0.93	HABETS AND HEINTZE (1981) †
0.82	ROVITHIS–LIVANOU (1992) ‡
1.04	ROVITHIS–LIVANOU (1992) §
0.74	FOR ALL W UMA (PRESENT WORK)
0.72	FOR W–SUBTYPE (PRESENT WORK)
0.65	FOR A–SUBTYPE (PRESENT WORK)

Notics:
†These data has been determined from Maceroni et al. (1985), Figure 1a.
‡This value deduced by the corresponding reference for the light curve. Analysis by W–D Code.
§This value has been found for the light curve analysis by Kopal's method by the corresponding references.

1. High correlation coefficient value ($r \simeq 0.8$) for wide mass range from 0.7 to 4.2 $M_\odot$.
2. The slope of the primary components in both W&A–subtype is the same (=0.62) as found by Lacy (1977) (see Figure 1 of Maceroni et al., 1985).
3. There are big differences between the slopes (the mass–radius relations) of the secondaries for both subtypes (see eqs. 15 & 17) as well as, between these secondaries and their primary components (see eqs. 14 & 16).

So, we can conclude that the mass–radius relation for the primary components of both W&A–subtypes of contact binaries may be written in the form:

$$R \propto M^{0.62}$$

Wilson (1978) introduced the orbital distance a_z, ($= F(\overline{R}_1 + \overline{R}_2)$, where $\overline{R_1}$ and $\overline{R_2}$ are the mean stellar radii and F is specified by the Roche geometry for a given value of mass ratio q and the degree of over–contact), on the assumption that both components are at ZAMS. These radii obey approximately the ZAMS mass–radius relation $R \propto m^{0.6}$. Kuiper's paradox (Kuiper, 1941) stated that both stars can not fit the ZAMS mass–radius relation and the one appropriate to components of a contact system from the Roche geometry at the same time. Van Hamme (1982) calculated an analogous function a_z on the assumption that only the primary (more massive) component fits the main sequence mass–radius relation $R \propto m^{0.8}$, in contrast with the remarks of Van't Veer (1979).

V. THE ORBITAL ANGULAR MOMENTUM

In the study of W UMa binaries, an attention has been devoted to the total angular momentum content of the contact system, (cf., Mochnacki, 1981; Van Hamme, 1982 and Maceroni et al., 1985). As the contact systems can not gain angular momentum during their life (Maceroni et al., 1985), this quantity can yield information about the evolutionary status.

The total angular momentum of Table 2 (in $dyn^{1/2}$. $gm^{3/2}$. $cm^{3/2}$) has been obtained from the formula:

$$J = \frac{M_1\,M_2}{M_1 + M_2}\left[G\,(M_1 + M_2)\,A\right]^{1/2}, \qquad (18)$$

Figure 6 a, b represents the system total angular momentum as a function of the total mass for both subtypes W&A of the W UMa binaries. A good correlation coefficient has been found with a least square quadratic fit for the dependence of J on total mass as shown in the Figure (6 a, b). The quadratic fit gives the following relations:

1. For W–subtype;

$$J_{total} = 0.46 - 0.46\,M_{total} + 0.86\,M^2_{total}, \qquad (19)$$

with $r_W = 0.96$ and $s_W = 0.27$.
2. For A–subtype;

$$J_{total} = 1.41 - 1.51\,M_{total} + 1.07\,M^2_{total}, \qquad (20)$$

with $r_A = 0.96$ and $s_A = 0.70$.
From Table 2 and Figure 6 a, b we notice the following:
1. The data points of A–subtype are concentrated in a narrow range from $J_i = 0.09$ to $J_f = 0.74$ with mass range from $M_i = 0.81$ to $M_f = 2.88$ except of the system V2150 Cyg which has a high value of both $J_{total} = 1.39$ and $M_{total} = 4.24$.
2. The data points of W–subtype are distributed in

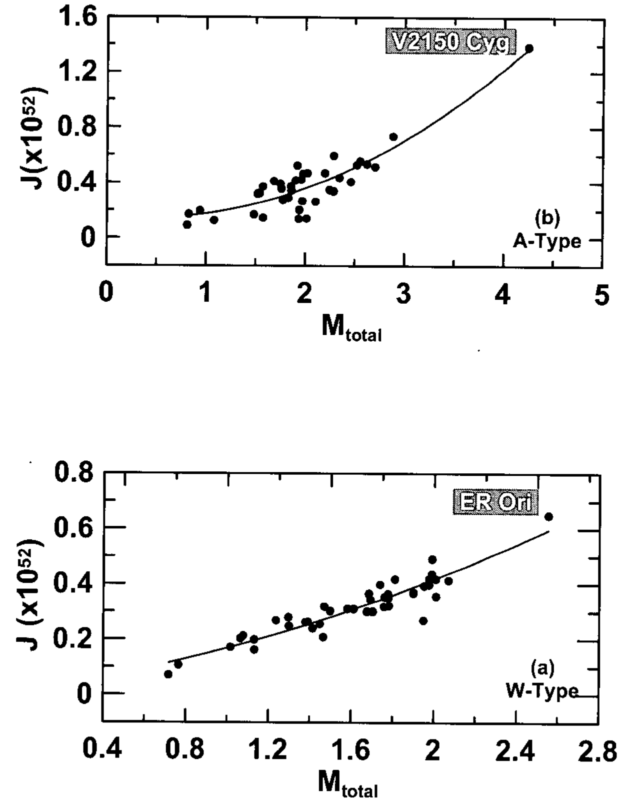

Fig. 6.— The system total angular momentum as function of the total mass for W&A–subtypes of the W UMa binaries. The solid line is the quadratic fit.

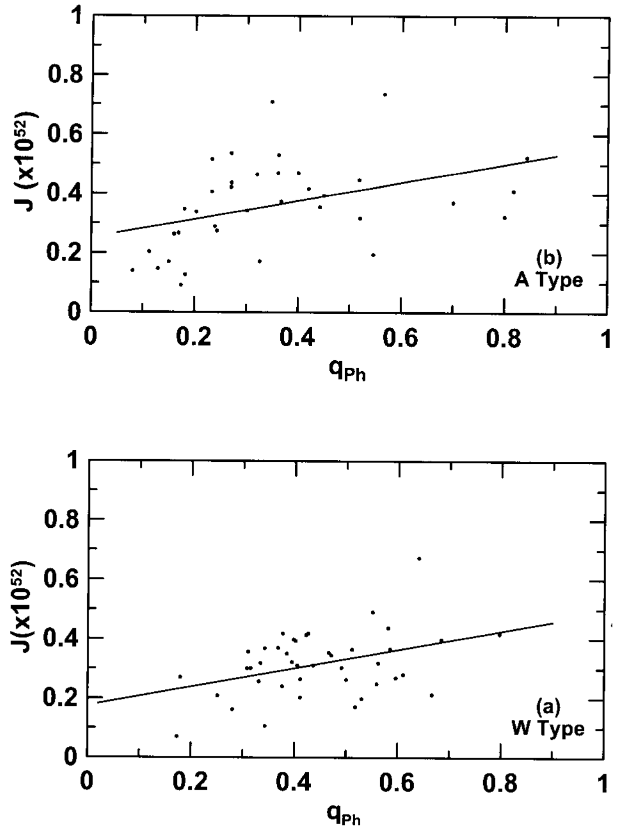

Fig. 7.— The relation of orbital angular momentum with the photometric mass ratio $q_{ph} = m_2/m_1$.

a wider range than A–subtype from $J_i = 0.07$ and $M_i = 0.72$ to $J_f = 0.41$ and $M_f = 2.07$ except for the system ER Ori which has the value $J = 0.67$ and $M_{total} = 2.60$.

3. The quadratic fit is found to be the best in both cases with a good correlation coefficient ($r = 0.96$) but the standard deviation of W–type is more reliable than that of A–type.

So, Figure 6 a, b suggests a quite simple view of W UMa systems as an essentially homogenous group of contact stars evolving from high to low mass through the mass transfer and angular momentum loss. The A–types are more massive than W–type, so, more faster in evolution.

Only the two systems, ER Ori and V2150 Cyg, have to be excluded from this view, since their orbital angular momentum is too high. The star ER Ori has been found as member of a multiple system (Kim et al., 2003).

On other hand, the relation between the orbital angular momentum and the photometric mass–ratio, $J - q_{ph}$, seems insensitive to the subtype of the system (Figure 7 a, b). The correlation coefficients have been found very low ($r_W = 0.40$) and ($r_A = 0.41$). These results confirm those by Maceroni et al.(1985) and disagree with the discovery by Van Hamme (1982) of a double slope of $J(q)$ for W–type and A–type systems, on which his W UMa's classification to four groups was based.

VI. REMARKS ON EVOLUTION STATUS

One of the difficulties for both subtypes of W UMa binaries is to infer the evolutionary status of the components from a direct comparison of the observed stellar parameters with those of single main–sequence stars.

Maceroni and Van't Veer (1996) assumed, in the study of the properties of W UMa contact binaries, that the W-type components were supposed to be ZAMS stars and the A–type more likely TAMS stars. With these assumptions the mass and luminosity were readily derived for each system finding, the total mass–total luminosity plane, the intersection of its "Kepler" and its evolutionary (ZAMS/TAMS) locus. Some authors have used this method to derive the absolute stellar parameters (e.g., González et al. 1996). This method was outlined also by Maceroni et al. (1985). But the method has to be modified to take into account the results of the studies of the angular momentum controlled evolution of close binaries (Maceroni and Van't Veer, 1996).

To get the reliability of this assumptions and evaluate this method, we employed the mass–luminosity relation of VandenBerg's (1985) grid models for main-sequence stars with solar abundances (Y=0.25, Z=0. 0169). Figure 8 a,b shows the individual masses M and luminosities L for the components (Primary and secondary from Table 2 a, b) of W&A–types. The M–L best linear relation (dashed lines) for each component (prim.&sec.) of both types are also shown.

From Figure 8 a, b we can notice the following:

1. Most of the observed primary components of both W&A–types have been located and distributed on pre–ZAMS or on ZAMS with some scattered systems. The M–L relation for primaries of W–type is;

$$\log L_{1W} = -0.14 + 1.81 \ \log M_{1W}, \qquad (21)$$

with $r_{1W} = 0.68$ and $s_{1W} = 0.23$.
And the M–L relation for primaries of A–type is;

$$\log L_{1A} = 0.34 + 1.51 \ \log M_{1A}, \qquad (22)$$

with $r_{1A} = 0.55$ and $s_{1A} = 0.34$.

2. The secondary components for both W&A–types have high scatter and not follow either ZAMS or TAMS, and their M–L fitting relations are poor.
3. Both components (primary and secondary) of both types (W&A) have approximately the same behaviour towards the ZAMS and TAMS. We also tried to use different stellar structure of VandenBerg's (1985) grid models for main–sequence stars with different solar abundances, but the same above remarks have been noticed.

Kalimeris and Rovithis–Livaniou (2001) found that the primary components for contact binary systems follow in general the ZAMS mass–luminosity relation although a large number is below it. They show graphically (Figure 10 in their paper) by observational data of a large sample of such systems that almost all secondaries have much larger luminosities than ZAMS, and in some cases even TAMS values; with bigger deviations to those of A–subclass. Figure 8 of the present work shows almost the same results as Kalimeris and Rovithis–Livaniou (2001).

So, the assumptions and the method that have been introduced by Maceroni and Van't Veer (1996) are not suitable to calculate or derive the individual masses or luminosities for the contact binary components. This is due to that the M–L relation of the ZAMS takes the form:

$$\log L_{ZAMS} \ = \ -0.23 \ + \ 4.47 \ \log M_{ZAMS}, \qquad (23)$$

with $r_{ZAMS} = 0.99$ and $s_{ZAMS} = 0.04$, which is quite different from both types.

In addition, there are no certain intersection between ZAMS and log M – log L plane to derive certain component's parameters with its "Keplarian". It has often been suggested that A–subtype systems could be considered as later evolutional stages of W–subtypes. That is mainly because their mean primary densities are smaller than those of ZAMS W-subtype stars (Wilson (1978)). But, in a view of the M–L relation, and the remark number 3 above, this suggestion is not confirmed. The densities of the components are dependent on the masses and the radii. Also the log M – log L relations are strongly dependent on the effective temperatures and on the component radii.

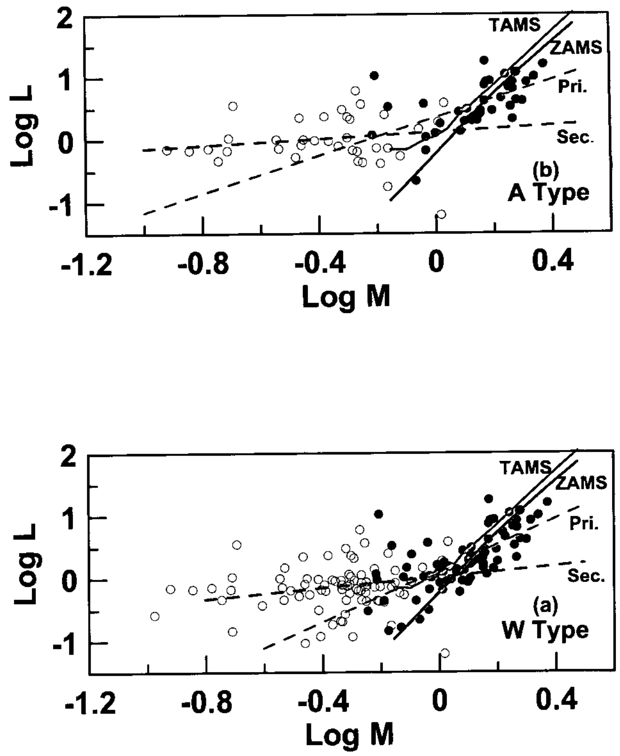

Fig. 8.— The primary (dark circle) and secondary (white circle) components for both W&A–subtypes of W UMa binaries on the mass–luminosity diagram corresponding to zero–age main–sequence (ZAMS) and terminal age main sequence (TAMS).

VII. SUMMARY AND CONCLUSION REMARKS

The present work has been based on recent photometric and spectroscopic data for a sample of 80 W UMa stars. The absolute parameters of these binaries have been computed. This sample contains 42 W–type and 38 A–type contact binaries. Some statistical relations for all the systems have been presented as follows:

1. The consistency of the photometric mass ratios with the spectroscopic mass ratios.
2. The correlation between the radii ratios and the photometric mass ratios.
3. The total mass–total luminosity relation $L \propto M^{\alpha}$ has been found for both types. The value of $\alpha = 2.04$ for all W UMa binaries, $\alpha = 1.6$ for W–type and $\alpha = 1.01$ for A–type. If we consider the relation for

the primary components only, the α values will equal to 1.8 and 1.5 for W&A–types respectively. The mass ratio–luminosity ratio relation has been studied and compared with the previous results (see Table 3)

4. The mass–radius relation for the primary components of both W&A–subtypes has been found to be in the form $R \propto M^{0.62}$. This result is nearly the same as the ZAMS mass–radius relation ($R \propto M^{0.60}$ and confirmed by Lacy (1977)). So, we can conclude that the primary components of both subtypes of W UMa binaries obeying approximately the ZAMS mass–radius relation not the main–sequence mass–radius ($R \propto M^{0.80}$) relation.

On the other hand, based on a new catalogue of photometric, geometrical, and absolute elements for 112 eclipsing binary system (Malkov, 1993) with both components on the main sequence with known photometric and spectroscopic orbital elements, Gorda and Svechnikov (1998) redetermined the mass–luminosity and mass–radius relations as follows:

$$\log L = 0.072 + 3.808 \log M, \ \text{for} M > 0.4 M_{\odot}, \quad (24)$$

$$\log L = -0.776 + 2.0 \log M, \ \text{for} M \leq 0.4 M_{\odot}, \quad (25)$$

$$\log R = 0.096 + 0.65 \log M, \ \text{for} M > 1.38 M_{\odot}, \quad (26)$$

$$\log R = 0.049 + 0.993 \log M, \ \text{for} M \leq 1.38 M_{\odot}, \quad (27)$$

From the present work, the mass luminosity relation (equation no. 8) and the mass luminosity relations (equations no. 14 and 16) are about the same as the above two equations (25) and (26) but in different mass range although, Malkov's (1993) Catalogue does not include W UMa systems. So according to the present work and the above equations of Gorda and Svechnikov (1998), we can conclude that the contact binaries (W UMa systems) behave as low mass ($\leq 0.398\ M_{\odot}$) eclipsing binaries with both components on the main–sequence in its mass–luminosity relation. While, the primary components of W UMa system behave as high mass ($> 1.38\ M_{\odot}$) eclipsing binaries with both components on the main–sequence in its mass–radius relation.

Malkov (2003) found that A–F main sequence eclipsing binaries have larger radii and/or higher temperatures than single stars. He explained these features by synchronization of such stars in close system that prevents them to rotate rapidly. So, we have found that the W UMa contact binaries may not be main sequence stars and they have their own mass–radius–luminosity relation.

The angular momentum, as a function of the total mass for both subtypes, has been studied and shows that each subtype behave as a homogenous group. This result confirms the classification of Binnendijk (1970) and can be added as a property for them. Also, this conflicts with the classification of Van Hamme (1982) for W UMa to be in four groups.

So we can conclude that both subtypes may behave as ZAMS in mass–radius relation but not necessarily behave as ZAMS or TAMS in mass–luminosity relations i.e., each subtype has its own properties.

The evolution status for both subtypes still need further theoretical stellar structure studies to confirm the observational parameters.

REFERENCES

Batten, A. H., Fletcher, J. M., & McCarthy, D. G., 1989, DAO, 17,1

Binnendijk, L.,1960, Properties of double Stars, VA, BQ821, B56

Binnnendijk, L., 1970, The orbital elements of W Ursae Majoris systems, VA, 12, 217

Binnnendijk, L., 1977, Synthetic light curves for contact binaries, 21, 359

Copeland, H., Jensen, J. O., & Jorgenson, H. E., 1970, A&A, 5, 12

Csizmadia, Sz., & Klagyivik, P., 2004, A&A, 426, 1001

Delfoose, X., Forveille, T., Ségransan, D., Beuzit, J. L., Udry, S., Perrier, C., & Mayor, M., 2000, A&A, 364, 217

Dworak, T. Z., 1975, AcA, 25, 383

González, J.F., Lapassat, E., Gómez, M., & Ahumada, J., 1996, PASP, 108, 338

Gorda, S. Yu, & Svechnikov, M. A., 1998, Astron. Rep., 42, 793

Habits, J. M. H. J. & Heintze, J. R. W., 1981, A&AS, 46, 193

Harris, D. L. Strand, K. A. A., & Worley, C. E., 1963, Stars and Stellar system, Vol III, Ed. G.P. Kuiper and B. M. Midllehurst, Chicago: University of Chicago Press, Chapter 15, 273

Hazlehurst, J., 1970, MNRAS, 149,129

Heintz, W. D., 1978, Double Stars /Revised Edition/ Dordrecht, D. Reidel Publishing Co. (Geophysics and Astrophysics Monography) , 15

Henry, T. J., Franz, O. G., & Wasserman, L. H., 1999, ApJ, 512, 864

Kähler, H., Matraka, B., & Weigert, A., 1986, A&A, 161, 296

Kähler, H., Matraka, B. & Weigert, A., 1987, A&A, 172, 197

Kähler, H.,2002a, A&A, 395, 899

Kähler, H., 2002b, A&A, 395, 907

Kähler, H., 2004, A&A, 414, 317

Kalimeris, A., & Rovithis-Livaniou, H., 2001, Odessa Astronomical Publications, 14, 33

Kim, C.-H. ,Lee, J. W., Kim, H.-I., Kyung, J.-M., & Koch, R. H., 2003, AJ, 126, 1555

Kopal, Z., 1959, Close Binary System, London, Chapman & Hall LTD

Kopal, Z., 1978, Dynamics of Close Binary Stars, Riedel Dordrecht, Holland, 17, 970

Kovaleva, D. A., 2001, Astron. Z., 78, 1104

Kuiper, G. P., 1941, ApJ, 93,138

Lacy, C. H., 1977, ApJSS, 34, 479

Lucy, L. B., 1968a,ApJSS, 151, 1123

Lucy, L. B., 1968b, ApJSS, 153, 877

Lucy, L. B., 1973, ApJSS, 22, 381

Maceroni, C., Milano, L., & Rosso, G., 1985, MNRAS, 217, 843

Maceroni, C., & Van't Veer, F., 1996, A&A, 311, 523

Malkov, O. Yu, 1993, Bull. Inf. Centre Donnees Stellaires, Vol. 42, 27

Malkov, O. Yu, Piskunov, A. E., & Shpillkina, D. A., 1997, A&A, 320, 79

Malkov, O. Yu, 2003, A&A, 402, 1055

Mengel, J. G., Demarque, P., Sweigart, A. V., & Gross, P. G., 1979, ApJS, 40, 733

Milone, E. E., 1968, AJ, 73, 708

Mochnacki, S. W., 1981, ApJ, 245, 650

Moss, D. L., & Whelan, J. A. J., 1970, MNRAS, 149,147

Moss, D. L., 1971, MNRAS, 153, 41

Osaki, Y., 1965, PASJ, 17, 970

Parenago, P. P., & Masevich, A. G., 1951, Trandy GAIS, 20, 81

Popper, D. M., 1980, ARA&A, 18, 115

Rovithis-Livaniou, H., Rovithis, P., & Bitzaraki, O., 1992, Ap&SS, 89, 237

Rucinski, S. M., 1973, AcA , 23, 79

Rucinski, S. M., 1974, AcA ,24, 119

Rucinski, S. M.,1978, Non stationary Evolution of Close Binaries, ed. A.N.Zytkow(Warsaw: Polish Scientific Publishers, 117

Russell, H. N., & Moore, C., 1940, The Masses of the Star, Chicago, 48, 28

Selam, S. O., & Demircan, O., 1994, MeSAI ,65, 405

Smith, R. C., 1983, Obs., 103, 29

VandenBerg, D. A., 1985, ApJS, 58, 711

Van Hamme, W., 1982, A&A, 105, 389

Van't Veer, F., 1979, A&A, 80, 287

Wilson, R. E., 1978, ApJ, 224, 885

References of Table 1. (a) (for W–type)

1- Batten, A. H. et al., 1989, DAO ,17
2- Barone, F., et al., 1993, ApJ, 408, 237
3- Binnedijk, L., 1984, PASP, 96, 646
4- Cerruti-Sola, M., et al., 1981, A&A, 101, 273
5- Goecking, K. D., et al., 1994, A&A, 289, 27
6- Hill, G., et al., 1989, A&A, 211, 81
7- Hrivnak, B. J., 1985, ApJ, 290, 696
8- Hrivnak, B. J., 1988, ApJ, 335, 319
9- Hrivnak, B. J., 1993, New frontiers in binary star research, 38, 269
10- Hendry, P. D., & Mochnacki, S. W., 1998, ApJ, 504, 978
11- Hilditch, R. W., 1981, MNRAS, 196, 305
12- Hilditch, R. W., Hill, G., & Bell, S. A., 1992, MNRAS, 255, 285
13- Kaluzny, J., 1984, AcA, 34, 217
14- Kaluzny, J., & Rucinski, S. M., 1986, AJ, 92, 666
15- Kim, C.-H., et al., 2003, AJ, 125, 322
16- Kim, C.-H., et al., 2003, AJ, 126, 1555
17- Kreiner, J. M., et al., 2003 A&A, 412, 465
18- Leung K. C., 1986, PASP, 88, 936
19- Lister, T. A., et al., 2000, MNRAS, 317, 111
20- Lu, W., 1991, AJ, 102, 262
21- Lu, W., 1993, AJ, 105, 646
22- Lu, W., & Rucinski, S. M., 1999, AJ, 118, 515
23- Lu, W., et al., 2001, AJ, 122, 402
24- Maceroni, C., et al., 1982, A&AS, 49, 123
25- Maceroni, C., et al., 1984, A&AS, 58, 405
26- Maceroni, C., et al., 1994, A&A, 288, 529
27- Marton, S. F., et al., 1989, MNRAS, 240, 931
28- McLean, B. J., & Hilditch, R. W., 1983 MNRAS, 203, 1
29- Metcalfe, T. S., 1999, AJ, 117, 2503
30- Milone, E. F., et al., 1991, ApJ, 370, 677
31- Milone, E. F., et al., 1987, ApJ, 319, 325
32- Nelson R. H., et al., 1995, AJ, 110, 2400
33- Niarchos, P. G., et al., 1994a, A&AS, 103, 99
34- Pribulla, T., et al., 1999a, CoSka, 29, 111
35- Pribulla, T., & Vanko, M., 2002, CoSka, 32, 79
36- Pych, W., et al., 2004, AJ, 127, 1712
37- Rucinski, S. M., et al., 2000, AJ, 120, 1133
38- Rucinski, S. M., et al., 2003, AJ, 125, 3258
39- Russo, G., et al., 1982, A&AS, 47, 211
40- Samec, R. G., 1990 PASP, 102, 994
41- Samec, R. G., & Hube, D. P., 1991, AJ, 102, 1171
42- Samec, R. G., et al., 1997, AJ, 113, 401
43- Schieven, G., et al., 1983, A&AS, 52, 463
44- Sezer, C., et al., 1985, Ap&SS, 115, 309
45- Vanko, M., et al., 2001, CoSka, 31, 129
46- Wang, Y., & Lu, W., 1990,A combined photometric and spectroscopic solution for AA Ursae Majoris, AcApS, 10, 248
47- Wilson, R. E., & Devinney, E. J., 1973, ApJ, 182, 539
48- Yang, Y., & Liu, Q., 1999, A&AS, 136, 139
49- Yang, Y., & and Liu, Q., 2003, A&A, 401, 631
50- Zhai, D., & Lu, W., 1988, ChA&A, 12, 223
51- Zhai, D., & Lu, W., 1989, ChA&A, 9, 208
52- Zola, S., et al., 2001, AcApS, 374, 164

References of Table 1 (b) for A–type

1- Akalin, A., & Derman, E., 1997, A&AS, 125, 407
2- Batten, A. H., et al., 1989, DAO, 17
3- Chochol, D., et al., 2001, CoSka, 31, 5

4- Djurasevic, G., et al., 1999, A&A, 343, 894
5- Goecking, K. D., & Duerbck, H. W., 1993, A&A, 278, 463
6- Hilditch, R. W., & Kig, D. J., 1988, MNRAS, 231, 397
7- Hilditch, R. W., et al., 1989, MNRAS, 237, 447
8- Hill, G., 1979, PDAO, 15, 297
9- Hrivnak, B. J., 1989, ApJ, 340, 458
10- Hrivnak, B. J., 1993, New frontiers in binary star research, 38, 269H Leung, I.S. Nha (eds.), ASP Conf. Ser., 38, 269
11- Hrivnak, B. J., et al., 1995, ApJ, 455, 300
12- Kaluzny, J., 1986, AcA, 36, 113
13- Klaci, R. & Derman, E., 2005, AN., 326, 342
14- Kreiner, J. M., et al., 2003, A&A, 412, 465
15- Lapasset, E. et al., 1987, Rev. Mer. A. Ap., 14, 402
16- Leung, K. C., & Schneider, D. P., 1978, ApJ, 222, 917
17- Liu Q., et al., 1996, A&AS, 118, 453
18- Lu, W., & Rucinski, S. M., 1999, AJ, 118, 515
19- Lu, W., et al., 2001, AJ, 122, 402
20- Lucy L. B., & Wilson R. E., 1979 ApJ, 231, 502
21- Maceroni, C., et al., 1982, A&AS, 49, 123
22- Maceroni, C., et al., 1990, A&A, 234, 177
23- Mauder, H., 1972 A&A, 17, 1
24- Milone, E. F., et al., 1995, AJ, 109, 359
25- Morris, S. L., & Naftilan, S. A., 2000, PASP, 112, 852
26- Niarchos, P. G., et al., 1994a, A&A, 292, 494
27- Özdemir, S., et al., 2002, A&A, 387, 240
28- Pribulla, T., et al., 1999b, A&A, 345, 137
29- Pribulla, T., et al., 2001, CoSka, 31, 26
30- Pribulla, T., & Vanko, M., 2002, CoSka, 32, 79
31- Rafert, J. B., et al., 1985, PASP, 97, 310
32- Rensing M. J., et al., 1985, AJ, 90, 767
33- Rodríguez, E., et al., 1998, A&A, 336
34- Rucinski, S. M., & Lu, W., 1999, AJ, 118, 2451
35- Rucinski, S. M., & Lu, W.: 2000, MNRAS, 315, 587
36- Rucinski, S. M., et al., 2000, AJ, 120, 1133
37- Rucinski, S. M., et al., 2001, AJ, 122, 1974
38- Rucinski, S. M., et al., 2002, AJ, 124. 1738
39- Twigg, L. W., 1979, MNRAS, 189, 907
40- Vanko, M., et al., 2001, CoSka, 31, 129
41- Vinkó, J., et al., 1996, MNRAS, 280, 489
42- Walker, R. L., & Chambliss, C. R., 1985, AJ, 1990, 346
43- Winkler, L., 1977, AJ, 82, 648
44- Yang, Y., & Liu, Q., 1999, A&AS, 144, 457