PERIOD–MASS RATIO RELATIONS FOR ECLIPSING BINARIES WITH PERIODS NOT EXCEEDING 5 DAYS

S. D. SINVHAL and J. B. SRIVASTAVA
Uttar Pradesh State Observatory, Naini Tal, India

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Abstract. The dependence of mass ratio of eclipsing binary systems on period has been studied. It has been found that semi-detached systems obey the relation $m_2/m_1 = 0.64 - 0.079P$ or $m_2/m_1 = 0.29 - 0.028P$ depending upon whether the mass ratio is >0.3 or <0.3. The mass ratio of detached systems generally appears to be independent of the period.

1. Introduction

Several statistical studies concerning relations between systemic parameters of binary systems have so far been made. These cover relationships between mass–luminosity (Kopal, 1959; McCluskey and Kondo, 1972), mass–radius (Kopal, 1959), period–density and period–spectral type (Plaut, 1953) and period–eccentricity (Bougue, 1974). However, no such study covering mass ratios [the ratio of the mass of the secondary (m_2) to that of the primary (m_1) component] and the period has so far been made. We report here results concerning one such study.

2. Data and Procedure

We discuss eclipsing binaries with periods not exceeding 5.0 days. The data concerning masses and periods have been taken from Giannone and Giannuzzi (1974), Kopal and Shapley (1956) and a few other sources. The spectral types have mostly been taken from Koch *et al.* (1970). These data are tabulated in Tables I, II and III.

A total of 98 eclipsing binary systems for which the mass ratios could be available have been considered. These have been classified into detached, semi-detached and contact systems. The data have been plotted in Figures 1, 2 and 3. The systems classified by Giannone and Giannuzzi (1974) as 'detached–semi-detached', 'cataclysmic' and 'R CMa type' have not been considered.

3. Discussions and Results

A. DETACHED SYSTEMS

An inspection of Figure 1 reveals that out of 45 detached systems considered, 32 have mass ratios exceeding 0.75, while the remaining thirteen systems have mass ratios between 0.30 and 0.70. The stars with a mass ratio exceeding 0.75 seem to divide themselves into three groups: the first group with periods less than $1^{d}.0$, the

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TABLE I

(A) Detached systems with mass ratio lying between the limits 0.75–1.0

Range of variation in apparent magnitude	System	Period (days)	$m_1/m_\odot$	$m_2/m_\odot$	m_2/m_1	*Sp*		Ref.
9.10– 9.65	YY Gem	0.814	0.56	0.56	1.00	dMle	dMle	1
5.14– 5.51	VV Ori	1.485	1.60	1.60	1.00	B1	B4	1
9.60–10.56	BH Vir	0.817	0.87	0.86	0.98	F8IV	G2V	1
9.14– 9.82	WZ Oph	4.184	1.13	1.11	0.98	F8V	F8V	1
7.2 – 7.8	Y Cyg	2.996	17.8	17.5	0.98	B0	B0	1
8.90– 9.57	GL Car	2.422	5.89	5.77	0.97	B3	B4	1
8.04– 8.50	CW Cep	2.729	9.98	9.77	0.97	B1	B1	1
9.8 –10.5	YY Sgr	2.628	2.36	2.29	0.97	A0	A0	1
1.93– 2.02	β Aur	3.960	2.34	2.25	0.96	A2	A2	1
5.70– 6.43	WW Aur	2.525	1.81	1.75	0.96	A7	A7	1
7.0 – 7.6	CD Tau	3.435	1.4	1.3	0.93	F5	—	5
5.82– 6.49	AR Aur	4.135	2.48	2.29	0.92	B9	B9	1
9.50–10.18	UV Leo	0.600	0.99	0.92	0.92	G0	G1 V	1
7.27– 7.49	ER Vul	0.698	1.23	1.13	0.91	G0V	G5V	1
9.41–10.10	VZ Hya	2.906	1.23	1.12	0.91	F5	F5	1
8.6 – 9.3	XY Cet	2.781	2.27	2.07	0.91	A0	A3	1
6.9 – 7.5	GK Cep	0.936	2.72	2.50	0.91	A2V	A2V	1
5.88– 6.58	U Oph	1.677	5.02	4.52	0.90	B5	B6	1
6.50– 6.80	AG Per	2.029	5.06	4.47	0.88	B5	B7	1
9.01– 9.79	V 382 Cyg	1.885	37.04	32.8	0.87	O9	B0	1
6.90– 7.12	AH Cep	1.775	16.1	13.9	0.86	B0.5V	B0.5	1
6.30– 6.79	BV 420	3.169	6.7	5.7	0.85	B3	B5	3
8.33– 9.08	TX Her	2.060	2.06	1.77	0.85	A5	F0	1
8.5 – 9.4	MR Cyg	1.677	3.06	2.60	0.84	B3	B9	1
6.30– 6.75	RS Cha	1.670	2.12	1.76	0.83	A5	A7	1
7.86– 8.46	V 451 Oph	2.197	2.38	1.98	0.83	A0	A2	1
7.81– 8.48	V 805 Aql	2.408	1.85	1.50	0.81	A2	A7	1
5.18– 5.36	σ Aql	1.950	6.80	5.40	0.79	B3	B3	1
8.3 – 9.2	TT Aur	1.333	6.73	5.32	0.79	B3	B3	1
8.6 – 9.5	AU Pup	1.126	2.77	2.19	0.79	A0	A4	1
9.7 –10.6	V 526 Sgr	1.919	2.11	1.66	0.78	A0	A0	1
9.20– 9.95	AI Cru	1.418	—	—	0.77	O	B	2

(B) Detached systems with mass ratio lying between the limits 0.30–0.70

Range of variation in apparent magnitude	System	Period (days)	$m_1/m_\odot$	$m_2/m_\odot$	m_2/m_1	*Sp*		Ref.
8.3 – 8.9	SZ Cen	4.108	—	—	0.67	A7III	—	2
9.80–10.59	SV Cam	0.593	1.15	0.76	0.66	dG3	dG5	1
9.34–10.24	RT And	0.629	1.50	1.00	0.65	F8	G9	1
6.40– 6.49	IM Mon	1.190	9.01	5.96	0.66	B5	B8	1
8.30– 9.18	V 477 Cyg	2.397	2.37	1.60	0.63	B5	B8	1
8.2 – 9.5	EK Cep	4.428	1.71	1.07	0.62	A0	F9	1
6.90– 7.57	EE Peg	2.628	1.94	1.20	0.61	A4V	F6	1
5.60– 6.01	YZ Cas	4.467	2.11	1.27	0.60	A3	F4	1
3.91– 4.41	ζ Phe	1.670	6.10	3.00	0.49	B6V	A0V	1
9.3 –10.1	ZZ Cep	2.142	4.10	1.90	0.46	B7	F0	1
5.00– 5.16	TU Cam	2.933	3.50	1.54	0.44	A0	A8	1
8.3 – 8.9	TW Cas	1.428	4.1	1.4	0.34	B9	G2	4
7.0 – 7.3	SZ Cam	2.698	21	6	0.29	O9.5	B0	2

Key to references:
1. Giannone and Giannuzzi (1974)
2. Kopal and Shapley (1956)
3. Schöffel (1973)
4. Kandpal (1975)
5. Srivastava (1976)

TABLE II

(A) Semi-detached systems with mass ratio >0.3

Range of variation in apparent magnitude	System	Period (days)	$m_1/m_\odot$	$m_2/m_\odot$	m_2/m_1	Sp		Ref.
10.02–12.99	XZ And	1.357	—	—	0.69	A0	K4	2
3.00– 3.28	μ^1 Sco	1.446	14.0	9.24	0.66	B1.5	B5	1
4.74– 5.25	V Pup	1.455	19.1	11.3	0.59	B1V	B3V	1
8.9–11.5	X Tri	0.972	1.72	1.00	0.58	A3	G3	1
10.09–13.20	Y Leo	1.686	1.91	0.63	0.52	A3	—	1
6.40– 7.58	V 505 Sgr	1.183	2.22	1.18	0.51	A2	G9	1
9.1 –11.9	RW Mon	1.906	—	—	0.50	A0	G7	2
6.63– 9.79	U Cep	2.493	3.19	1.53	0.47	B8	G8III	1
7.2 – 8.2	AI Dra	1.199	2.18	1.03	0.47	A0V	F9	1
7.30– 8.39	TV Cas	1.813	3.10	1.39	0.44	B9	F6	1
8.7 – 9.8	W UMi	1.701	2.68	1.19	0.44	A3	G8	1
4.91– 5.96	δ Lib	2.327	2.96	1.31	0.44	A0	G8	1
7.38– 9.20	Z Vul	2.455	5.40	2.27	0.42	B3–4	A2–3	1
8.2 –10.5	TW Dra	2.807	2.08	0.87	0.41	A6	K0	1
6.66– 7.35	LY Aur	4.003	21.6	8.1	0.37	—	—	3
7.04– 8.35	U CrB	3.452	6.76	2.56	0.37	B6	K0	1
6.31– 9.92	U Sge	3.381	4.27	1.60	0.37	B7	G2IV	1
10.35–11.23	VV UMa	0.687	1.94	0.45	0.37	A0	G8	1
4.60– 5.28	u Her	2.051	8.01	2.82	0.35	B2	B5	1
6.90– 7.63	RS Vul	4.477	4.65	1.45	0.31	B5V	G2IV	1

(B) Semi-detached systems with mass ratio <0.3

Range of variation in apparent magnitude	System	Period (days)	$m_1/m_\odot$	$m_2/m_\odot$	m_2/m_1	Sp		Ref.
7.9 – 8.5	IM Aur	1.247	2.97	0.89	0.29	B9	K3	1
10.2 –11.1	XY Cep	2.775	3.8	1.1	0.28	B8	—	4
6.38– 7.89	RZ Cas	1.195	1.81	0.50	0.27	A2	K0	1
9.05–10.21	UX Her	1.549	1.88	0.49	0.26	A3	K8	1
10.1 –10.6	RW CrB	0.726	1.60	0.42	0.26	F0	—	1
10.8 –14.1	Z Dra	1.357	1.82	0.44	0.24	A5	K5	1
9.6 –11.0	RX Hya	2.282	1.68	0.40	0.23	A8	K0	1
10.5 –12.2	Y Cam	3.306	2.33	0.50	0.21	A7V	M2	1
8.8 –11.1	TW And	4.123	1.81	0.39	0.21	dF0	K3	1
9.7 –12.7	W Del	4.806	2.36	0.47	0.19	A0e	G5	1
8.0 –10.0	S Equ	3.436	2.96	0.36	0.12	B9V	G3	1
10.1 –12.0	TY Peg	3.092	1.5	0.23	0.15	A2	K0	2
8.48– 9.21	AS Eri	2.664	2.02	0.25	0.12	A0	G6	1

Key to references:

1. Giannone and Giannuzzi (1974)
2. Kopal and Shapley (1956)
3. Andersen *et al.* (1974)
4. Unpublished data by the author

TABLE III

Contact systems

Range of variation in apparent magnitude	System	Period (days)	$m_1/m_\odot$	$m_2/m_\odot$	m_2/m_1	Sp		Ref.
8.80– 9.50	YY Eri	0.321	0.97	0.93	0.95	G5	G5	1
10.20–11.23	SW Lac	0.321	1.05	0.89	0.84	G3p	G3p	1
10.43–10.93	XY Leo	0.284	0.46	0.37	0.80	K0V	K2	1
9.70–10.31	U Peg	0.375	1.33	1.07	0.80	F3	F3	1
8.30– 9.06	W UMa	0.334	1.29	0.86	0.66	F8	F8	1
10.40–11.27	AB And	0.332	1.82	1.13	0.62	G5	G5	1
9.30– 9.98	ER Ori	0.423	0.47	0.28	0.59	G3	G3	1
6.70– 7.22	S Ant	0.648	1.65	1.03	0.55	A8	A7.5	2
10.5 –11.5	RZ Tau	0.416	1.71	0.92	0.53	F0	F0	1
9.60–10.42	TW Cet	0.317	1.29	0.67	0.51	G5	G5	1
6.50– 7.10	i Boo	0.268	0.96	0.49	0.51	G2	G2	1
10.45–10.78	TX Cnc	0.383	1.29	0.65	0.50	F8V	F8	1
10.96–11.66	RZ Com	0.339	1.64	0.78	0.47	K0	K0	1
9.60–10.31	AH Vir	0.408	1.38	0.58	0.42	K0	K1	1
8.40– 8.98	V 502 Oph	0.453	1.53	0.61	0.39	F9V	G2V	1
8.6 – 9.1	V 1073 Cyg	0.786	1.37	0.47	0.34	A3m	F0	1
7.60– 8.09	V 566 Oph	0.410	1.30	0.44	0.33	F3	F8	1
7.80– 8.21	VW Cep	0.278	0.79	0.26	0.32	G5	K1	1
8.77– 9.36	AG Vir	0.643	2.16	0.67	0.31	A2	F5	1
8.83– 9.32	AK Her	0.422	1.43	0.43	0.30	F2	F9	1

Key to references:
1. Giannone and Giannuzzi (1974)
2. Kopal and Shapley (1956)

second with periods between $1^{\mathrm{d}}.0$ and $2^{\mathrm{d}}.4$ and the third with periods between $2^{\mathrm{d}}.4$ and $5^{\mathrm{d}}.0$. While little can be said of the first group due to its small sample size, the second group has a mean mass ratio of 0.84 and the third group of 0.94. Apart from the above statement, for all these systems the mass ratio appears to be largely independent of the period. Further, the components of detached systems with mass ratios between 0.75 and 1.0 have similar spectral types, while for mass ratios less than 0.70 the components normally differ by about one spectral class, the secondary being of a spectral type later than that of the primary.

B. SEMI-DETACHED SYSTEMS

A total of 33 semi-detached systems have been considered (See Table II). These systems are divided into two groups. The first group, with mass ratios >0.3, satisfy the relation $m_2/m_1 = 0.64 - 0.079P$ on the period–mass ratio plot (Figure 2). The secondary components of this group all have masses greater than one solar mass, and their spectra are generally earlier than K0.

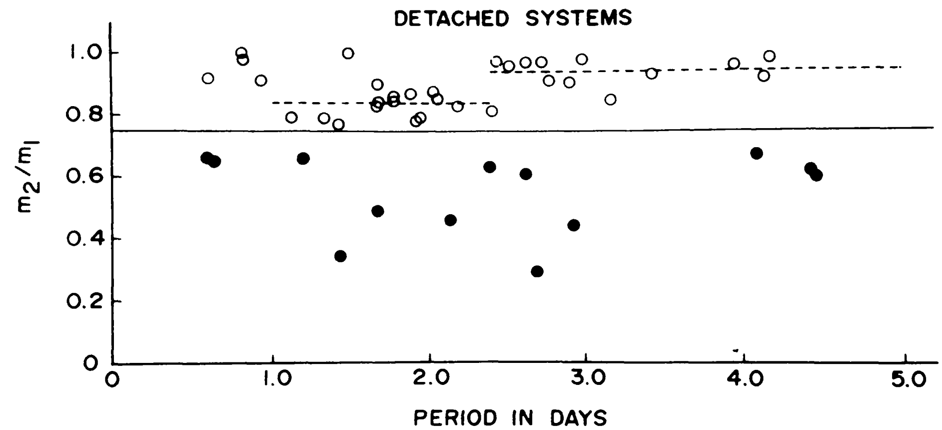

Fig. 1. Period–mass ratio plot for detached systems.

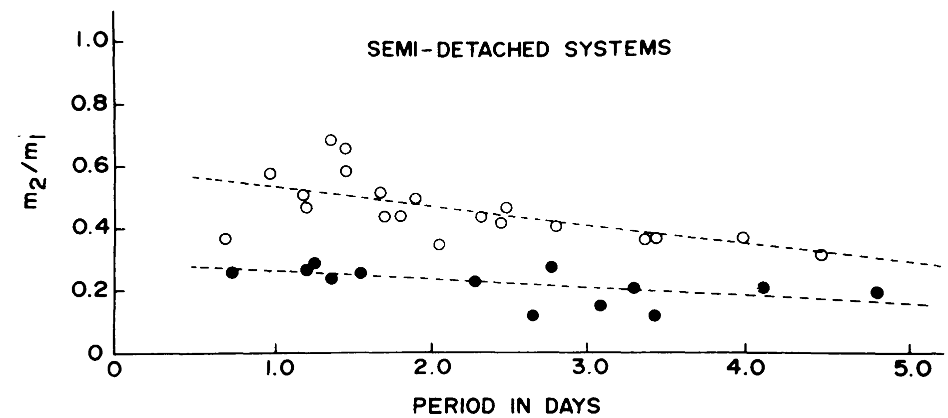

Fig. 2. Period–mass ratio plot for semi-detached systems.

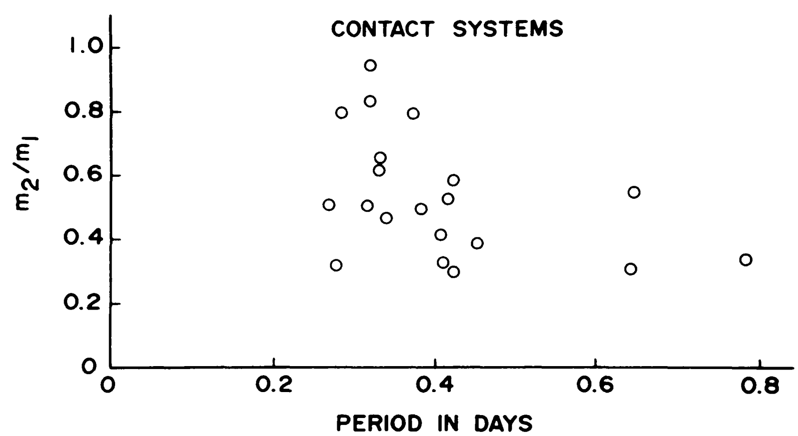

Fig. 3. Period–mass ratio plot for contact systems.

The second group of semi-detached systems having mass ratios <0.3, satisfy the relation $m_2/m_1 = 0.29 - 0.028P$. The secondaries of these systems have masses mostly around 0.5 $m_\odot$ or less (only in very few cases is this limit exceeded), and belong to spectral class K or later.

The above relations can be helpful in determining the mass ratio for semi-detached systems, without recourse to spectroscopic observations. If the light curve of an eclipsing binary shows great disparities between alternate minima and if the primary minimum shows a constant phase, it may be assumed that the system is semi-detached and the mass ratio can be reasonably estimated from the above relations from a knowledge of its period and the photometric spectral type of the secondary component.

In this context we note that the semi-detached binary stage usually occurs at the phase of slow mass transfer which lasts some 10^6–10^9 years. During this phase the (less massive) secondary component transfers mass to the primary component through the Lagrangian point L_1, due to which the mass ratio m_2/m_1 decreases and, consequently, the period increases (Huang, 1963). The two relations given above conform to this theoretical picture.

C. CONTACT SYSTEMS

The data for contact systems are rather scanty. Mostly the contact systems have periods lying within the limits $0\overset{d}{.}23$–$0\overset{d}{.}43$. Only three of the 20 systems considered have periods between $0\overset{d}{.}6$ and $0\overset{d}{.}8$. The mass ratios of the systems vary from 0.3 to 0.95, though for most of the systems the value is below 0.7. From the data in hand there is apparently no relationship between period and mass ratio for such systems.

4. Selection Effects

The following table gives the distribution of apparent magnitudes, at primary minimum, for the 98 systems discussed above:

Apparent magnitude at primary minimum	No. of systems
1.0– 5.9	13
6.0– 6.9	15
7.0– 7.9	13
8.0– 8.9	23
9.0– 9.9	20
10.0–10.9	14
Total	98

Thus in the above investigation there appears to be no bias in favour of apparently bright systems.

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