PROPERTIES OF THE SUBGIANTS IN THE ECLIPSING BINARY SYSTEMS OF DIFFERENT TYPES

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ABSTRACT. The properties of subgiants from eclipsing binary systems are considered . The necessity of their dividing into different groups on masses and orbital periods is suggested. It allows to find the significant correlations between the main characteristics of supergiants and the corresponding systems' characteristics. It is shown that low-mass subgiants from short-period systems quickly lose the mass. They possess the largest temperature and radii excesses, but with mass and period increasing the temperature excesses are replaced by the temperature deficiency, which are maximal for massive subgiants of AR-systems.

Key words: stars, eclipsing binary stars, subgiants.

I. Subgiants can be found in three different classes of eclipsing binary systems (Svechnikov, 1986): semidetached (SD-systems), with detached subgiant (DS-systems) and AR-systems. In SD and DS - systems more massive star belongs to main-sequence and subgiant is an evolved companion. Shain (1928) described the main properties of the subgiants:

a) they have less masses than second star of the pair,

b) they do not fit "mass-luminosity " relation, showing greater luminosity excesses,

c) they have earlier spectral types than main-sequence stars with the same masses;

d) their luminosity excesses increase with decreasing of the mass ratio q for stars of the system.

Further it was shown that subgiants in SD-systems fill in and DS and AR-systems do not fill in their Roche lobes.

Let us consider the general properties of the subgiants in SD, DS and AR-systems. In Table 1 we give averaged characteristics of the subgiants from SD, DS and AR-systems that were derived on the base of the catalogue (Karetnikov and Andronov, 1989). Designations are the following: n-number of the stars, lg A-distance between the stars, lg R-radius of the star, lg M and $q = M_2/M_1$ - mass and mass ratio respectively, Δ lg R and Δ lg T - averaged radius and temperature excesses for subgiants. Here we also give the mean values of averaging procedure Δ. R_iA - degree of the Roche lobe filling. This value is calculated using formula (Iben and Tutukov, 1984):

$$RR_i = 0.52 \cdot A \cdot (M_i/M)^{0.44},$$

where $M = M_1 + M_2$ and $R_iA = R_i/RR_i$.

The differences in degrees of the Roche lobe filling are caused by the differences in the evolution of these stars under the different initial characteristics of stellar pairs: their masses and sizes of the orbits. Using the data from Table 1 we immediately reveal that mean sizes of orbits A are close to 13.2 $R_\odot$ for SD-systems, 32.4 $R_\odot$ for DS and 15.5 $R_\odot$ for AR-systems. Detached subgiants belong to the more wide systems. Nevertheless, it should be noted that observed sizes of orbits for numerous class of DS and AR-systems embrace all possible values and therefore such a comparison is not completely correct.

II. Using models from (Mengel et.al., 1979), we can construct the evolutionary tracks for stars of the different masses up to subgiants phase. Resulting "luminosity-temperature" diagram is shown in Fig.1. It is seen that depending upon the mass all the tracks can be divided into two groups:

1) those of low-mass stars, i.e. $M_i < 1.5M_\odot$ and

2) of intermediate-mass stars: $1.5M_\odot < M_i < 3.5M_\odot$.

Note that more massive subgiant are not numerous and therefore their tracks in (Mengel et.al., 1979) are not calculated. Stars from the first group show a smooth increasing of the luminosity; they quickly pass to giant stage practically without any delay. Stars from the second group demonstrate sinuous evolutionary tracks having the parts of strong increasing and decreasing of the temperature. Accordingly to (Masevich and Tutukov, 1988), differences in evolutionary tracks of stars with different masses are defined by different processes of the energy production. Let us isolate on Fig.1 the following parts of the tracks: aa) formation of burnt stellar core, bb) core contraction, cc) helium core burning, while the star evolves to giant branch. The part "aa" is transitional stage between dwarfs and subgiants. Therefore, properly subgiant phase is referred to "bb" and "cc" regions of the diagram, where the luminosity and temperature suffer very complicated changes.

It is clear that if not taking into account the division

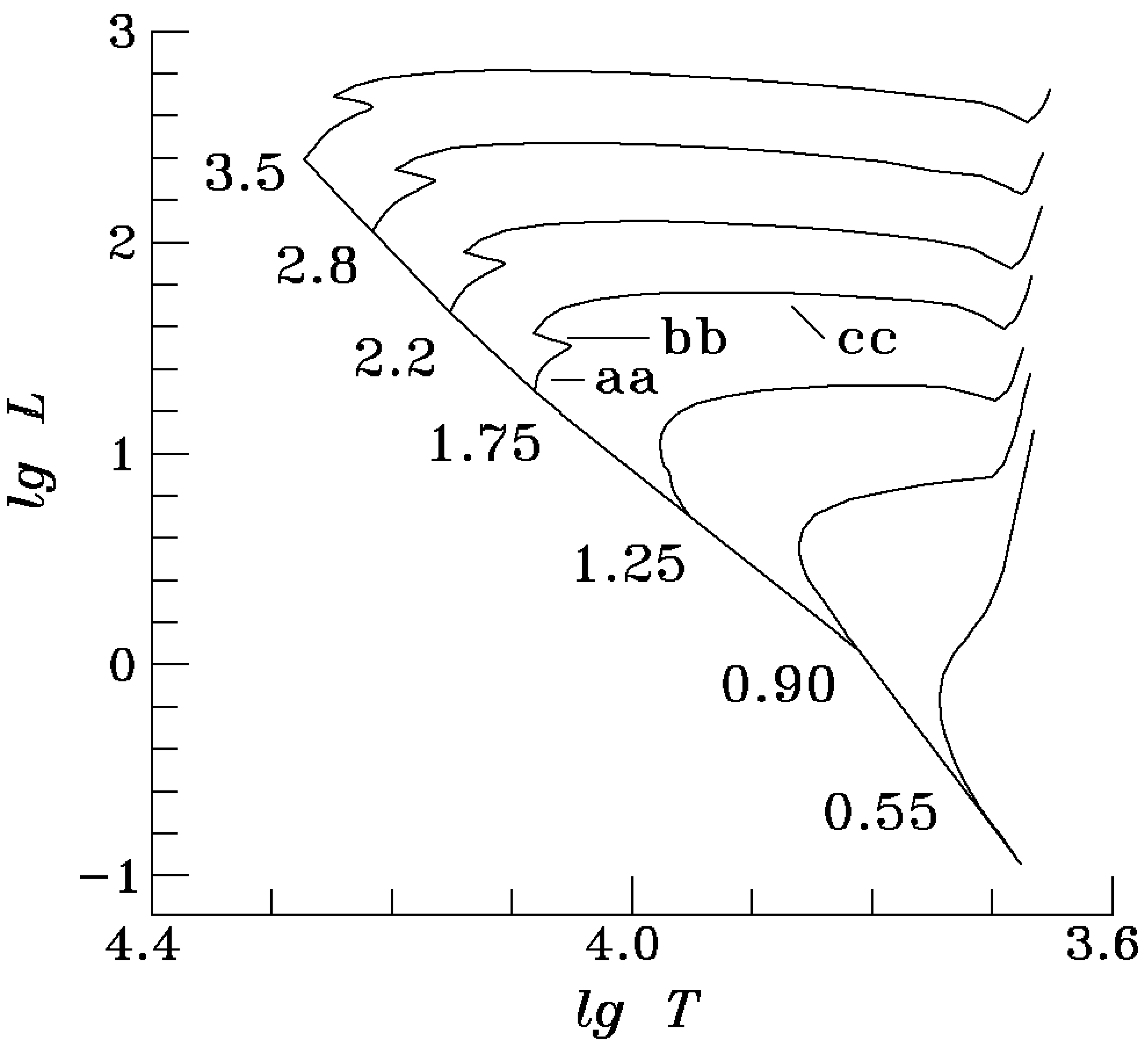

Figure 1.

of subgiants on their masses, we can intermix completely different relation for their masses and luminosities. Probably, only stars located within "bb" region can be considered as subgiants, while stars of "aa" region have the properties of main sequence stars and those of "cc" region resemble giants. Therefore, it is necessary to separate this stars and to search for some relation within separated groups. It seems, that such a separation has never been done and different kinds of objects were ranked as subgiants.

An important feature of the stars constituting SD and DS-systems is confidently observed gas streams that lead to a great mass loss from subgiant. Accordingly to observations, some part of the lost material is accreted by neighbor star of the V luminosity class. Processes of gas loss and subsequent accretion lead to the changes in the mass ratio q of the system. Results of investigation show that mass ratio q correlates with subgiant mass: for SD systems coefficient is 0.69, for DS - it is negligible and for AR systems k=0.82. This fact obviously testifies about mass ratio change for the systems.

Another important factor which also requires a separation of the stars on their masses is the mechanism (or mechanisms) operation that leads to changes of the orbital momentum and semi-major axis of the system. It is know that stars with mass less than 1.5 $M_\odot$ possess a rather strong magnetic wind which favors to the angular momentum loss and therefore leads to semi-major axis decreasing. All the stars can have an usual stellar wind which is stronger for more massive stars. Such a wind presence can increase the distance between the stars. An interaction of these winds must influence on the main parameters of the stellar system.

III. Let us isolate among the different kinds of eclipsing binaries (SD, DS and AR systems) the following clusters:

– cluster "a" contains the stars with masses less than $1.5M_\odot$;

– cluster "b" consists of the stars with masses $1.5M_\odot < M_1 < 10M_\odot$ and $M_2 < 1.5M_\odot$;

– cluster "c": stars with masses $1.5M_\odot < (M_1 + M_2) < 10M_\odot$;

– cluster "d" consists of the stars with $M_1 > 10M_\odot$ and $M_2 > 1.5M_\odot$;

Here M_1 and M_2 are the masses of the components and $M_1 + M_2$ is a total mass of the system.

We can also specify subclusters using the distribution on orbital periods:

– subcluster "1a" contains the systems of "a" cluster with $P < 1.5^d$;

– subcluster "2a" - with $1.5^d < P < 2.5^d$;

– subcluster "3a" - $2.5^d < P < 3.5^d$;

– subcluster "4a" - $3.5^d < P < 6^d$;

– subcluster "5a" - P more than 6^d.

Detailed classification for "b","c" and "d" clusters can be made in the similar way. Note that each cluster of DS-a, DS-c, AR-b and AR-c types contains only one star, therefore they are excluded from this consideration.

As it shown in (Karetnikov, 1990), such a separation of the stars into different groups (clusters) with simultaneous accounting of any possible mechanisms of mass and angular momentum transfer gives as a possibility to prognosticate the possible evolutionary scenario for stars of system. For example, M.A. Svechnikov proposed that subgiants of AR systems are formed from low-mass binary systems with great orbital period initially containing main-sequence stars that never filled in their Roche lobes. Having rather slow evolution they became subgiants without suffering the stage of the "role-change" (Crawford, 1955), which is usual phase for SD and DS systems.

IV. Let us analyze the subgiant group properties using their separation on the classes, clusters and subclusters. One can use the characteristic of the stars from catalogue (Karetnikov and Andronov, 1989). Firstly, we investigate the relations between mass ratio q and subgiant masses. Then we investigate the relation between radius and temperature excesses of subgiants and their masses, mass ratio q and system sizes A. For this aim we will use a formula $y = a + b \cdot x$, where argument will be a subgiant mass M_i or the total mass M of the system, or mass ratio q or orbital size lg A. As a function we will use mass ratio q and excesses of the radius $\Delta \lg R$ and temperature $\Delta \lg T$.

Results of comparison are gathered in Table 2, where we give the coefficients A and B, and sigma values $\sigma(A)$ and $\sigma(B)$ (significance level more then 0.95). Here we also give the correlation coefficients k and $\sigma(k)$. One can see that correlations between the mass ratio q and mass of the less massive star M_2 in SD and DS are most significant. Nevertheless, in some cases, the correlations have a small significance (less than 0.95) as for SD-c and SD-d clusters. They are not included in Table 2. On the corresponding places we give the blanks.

Obtained results indicate the clear decreasing of the subgiant mass in SD and DS systems. Most rapid mass decreasing (and correspondingly q-value decreasing) takes place for SD-a and especially for subcluster SD-1a. For cluster DS-b subgiant mass decreasing is more rapid than for cluster SD-b. For AR-a cluster the mass decreasing is going more rapidly. This poses a question about mechanism of mass loss in AR systems which consist of two "detached" subgiants. It is seen that with subgiant mass growth and increasing of the orbital period, the rate of q change generally slows down. The q value clearly correlates with subgiant masses. The level of significance for such a correlation often achieves 1. There also exists rather high significance for two correlation between q and M_1 in SD system and subcluster SD-2b and for four correlation of "q-M" type. In this case B coefficients have the same sign which means that with decreasing of q value the mass of the system has a tendency to be decreased. The changes of q value are of evolutionary character. Last two facts are of great interest, because an interpretation of the mass transfer for detached subgiants is now complicated.

Let us consider subgiant luminosity characteristics separating them on their contribution of the radii and temperatures in resulting luminosity. We will use for calculations the mean relation "mass-radius" and "mass-temperature" (Karetnikov, 1991). As before we employ the linear formula, where a function will be either radius excess $\Delta \lg\ R$ or $\Delta \lg\ T$ and argument is subgiant mass M_2. Results are gathered in Tables 3 and 4. These data allow to make a conclusion that proposed separation of the subgiants on the groups gives a possibility to investigate reliably the group properties of the subgiants from different kinds of stellar systems and to separate the systems having different characteristics.

It should be noted that subgiant luminosity excesses demonstrate a complex behavior. The fact of luminosity excess increasing with subgiant mass increasing is well established. One can also note an increasing of luminosity excess with an increasing of system size. It is obviously seen that DS systems having the least subgiant masses, at the same time possesses the greatest luminosity excesses mainly due to radii excesses. In SD systems, in average, the radii excesses are less, but temperature excesses are slightly greater. Nevertheless, for low-mass subgiants of SD systems with great orbital period the radii excesses as well as temperature excesses are dominating among all subgiants from the binary systems. An exceptional position of DS systems is excogitated.

The coefficients k(RA), k(RM) and k(Rq) define the reliability of mutual connections of the subgiant radii excesses $\Delta \lg\ R$ with distance between the stars ($\lg\ A$), subgiant masses ($\lg\ M$) and mass ratio q. Coefficients k(TA), k(TM) and k(Tq) give the reliability of connection between the temperature excesses $\Delta \lg\ R$ of subgiants and those of systems. A dependence between radii and temperature excesses and system parameters has been searched in the form $y = a + b \cdot x$. All calculated values are accompanied with standard deviation values. The designation are the same as above.

V. Data from Table 3 clearly testify that correctness of the made supposition concerning the presence of the great radii excesses in detached subgiants takes place only for DS systems. For detached subgiants and AR systems the radii excesses are minimal. Most of SD systems confirm the conclusion about radii excesses increasing with subgiant mass decreasing and with increasing of the system size. It is seen very well from the comparison of the radii excesses for SD systems when dividing them on the mass groups. Note that among SD systems there are subgiants having very great radii excesses (subcluster SD-4b) and subgiants with small radii excesses (subcluster SD-1b).

For subgiants of SD systems the reliable relations between radii and system sizes are obtained. An exception can be made only for SD system of the great masses. One can also assess as reliable the formula for relation between radii and mass excesses in subgiants of SD-b group and their separation on the base of orbital period value. In the last case, the most short-period SD-1b pairs give the less reliable results than low-mass systems with long period. The same picture takes place when we compare the radii excesses with mass ratio q values for this type of stars.

After averaging procedure for all subgiants of AR class, the temperature deficiency is seen. Such a deficiency is more pronounced for more massive companion. Similar situation takes place for SD systems with subgiant mass greater than $1.5 M_{\odot}$. Moreover, for more massive SD systems such a deficiency is two times less, than for AR systems. Subgiants from DS systems possess the small temperature excesses, while in subgiants from SD systems excesses are seen for low-mass systems. One can see from the Table 1 that, if dividing the SD-b into groups according to orbital period, the temperature excesses increase with the increasing of system sizes $\lg\ A$. This increase is caused by the decrease of the subgiant mass (the correlations with $\lg\ M$ and q are statistically significant). The dependencies of $\Delta \lg\ T$ on $\lg\ A$ are not significant.

Comparison of the group average values of $\Delta \lg\ R$ and $\Delta \lg\ T$ shows, that they contribute to the luminosity excess differently. The contribution in this excess of the radius exceeds the contribution of the temperature excess of a subgiant star by hundreds times. Therefore the temperature deficiency, which is sometimes detected for subgiants, does not significantly affect the common luminosity excess. At the same time (as it was noted by Karetnikov and Andronov (1989)), the temperature excess for a SD-class correlates with the luminosity excess better, than the radius excess. This fact is confirmed by the values of the correlation coefficients listed in Tables 3 and 4. Unfortunately, the correlation between the temperature excess and the sizes of SD-systems, which was suggested by Karetnikov (1990), was not found here.

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Table 1. Mean characteristics of the subgiant stars in close binary systems and r.m.s. deviation of the data from the mean.

Type of systems	n	$\lg A$	$\lg R$	$R_i A$	$\lg M$	q	$\Delta \lg R$	$\Delta \lg T$
SD	82	1.12	0.54	1.00	-0.06	0.31	0.48	0.06
		.26	.26	.10	.42	.15	.22	.15
DS	11	1.51	0.74	0.67	-0.15	0.29	0.73	0.05
		.14	.16	.16	.19	.09	.19	.13
AR1	12	1.19	0.47	0.53	0.15	0.89	0.27	-0.10
		.10	.21	.19	.09	.16	.20	.08
AR2	12	1.19	0.43	0.51	0.08	0.89	0.26	-0.06
		.10	.18	.20	.13	.16	.21	.07
SD-a	6	0.74	0.15	1.03	-0.46	0.26	0.33	0.17
		.14	.12	.06	.18	.11	.16	.11
SD-b	58	1.08	0.50	1.01	-0.20	0.28	0.52	0.08
		.20	.18	.09	.25	.12	.22	.14
SD-c	12	1.23	0.60	1.00	0.31	0.36	0.38	-0.03
		.12	.10	.07	.09	.10	.09	.14
SD-d	6	1.69	1.13	0.93	0.95	0.55	0.41	-0.05
		.18	.26	.21	.34	.28	.27	.16
SD-1b	15	0.84	0.29	0.98	-0.13	0.38	0.26	0.04
		.08	.10	.10	.16	.11	.10	.11
SD-2b	14	1.03	0.45	1.00	-0.19	0.29	0.46	0.07
		.06	.08	.06	.24	.12	.11	.12
SD-3b	14	1.15	0.55	1.04	-0.21	0.23	0.58	0.09
		.08	.11	.05	.26	.08	.07	.15
SD-4b	15	1.32	0.70	1.03	-0.29	0.22	0.78	0.12
		.10	.09	.12	.28	.09	.16	.15
DS-b	9	1.56	0.79	0.64	-0.17	0.29	0.77	0.05
		.66	.32	.15	.04	.08	.17	.15
AR-a	10	1.10	0.45	0.52	0.05	0.89	0.26	-0.07
		.30	.16	.20	.11	.17	.15	.08

Clusters DS-a, DS-c contain one star: RU Cnc and Z Ori, respectively; clusters AR-b, AR-b contain also one star: SZ Psc and SZ Cen, respectively.

Table 2. Values of the coefficients A and B, correlation coefficient K, standard errors σ. Here $M = M_1 + M_2$ is the mass of the binary, M_1 and M_2 are masses of the primary and secondary stars, respectively. The dash means the absence of significant correlation.

Type of	Number	$q = A + B \cdot M$			$q = A + B \cdot M_1$			$q = A + B \cdot M_2$		
systems		A	B	k	A	B	k	A	B	k
SD	82	+0.24	+0.01	0.60	+0.24	+0.02	0.51	+0.26	+0.03	0.69
		.02	.00	.09	.02	.00	.10	.01	.00	.08
SD-a	6	-0.50	+0.42	0.85	-	-	-	+0.02	+0.64	0.99
		.24	.13	.26				.02	.04	.06
SD-1a	4	-0.63	+0.49	0.90	-	-	-	+0.02	+0.65	0.99
		.32	.17	.31				.02	.05	.07
SD-b	58	-	-	-	-	-	-	+0.12	+0.23	0.71
								.02	.03	.09
SD-1b	12	-	-	-	-	-	-	+0.09	+0.38	0.84
								.07	.08	.17
SD-2b	10	+0.03	+0.09	0.87	0.00	+0.14	0.78	+0.13	+0.24	0.95
		.06	.02	.18	.10	.04	.22	.03	.03	.11
SD-3b	17	-	-	-	-	-	-	+0.11	+0.18	0.64
								.04	.06	.20
SD-4b	12	-	-	-	-	-	-	+0.14	+0.14	0.81
								.03	.03	.18
SD-5b	6	RY Per excluded				-	-	-0.01	+0.45	0.96
								.03	.06	.13
DS	11	-	-	-	-	-	-	-	-	-
DS-b	9	-	-	-	-	-	-	+0.01	+0.42	0.89
								.06	.08	.17
AR	12	-	-	-	-	-	-	+0.57	+0.25	0.58
								.14	.11	.26
AR-a	10	-	-	-	-	-	-	+0.25	+0.55	0.82
								.16	.14	.20

Table 3. Coefficients of correlation between radius excesses $\Delta \lg R$ and $\lg A$, $\lg M$, $\lg g$ in the case when k is statistically significant. Standard deviations are also given. Dash means that significance level is negligible.

Type of systems	n	a_1	b_1	$k(RA)$	a_2	b_2	$k(RM)$	a_3	b_3	$k(Rq)$
SD	82	0.00	0.42	0.51	0.46	-0.22	-0.42	0.07	-0.73	-0.70
		.09	.08	.10	.02	.05	.10	.05	.08	.08
DS	11		-			-			-	
AR1	12		-			-			-	
AR2	12		-			-			-	
SD-a	6	-0.46	1.08	0.93		-			-	
		.15	.20	.18						
SD-b	58	-0.50	0.94	0.83	0.41	-0.54	-0.68	0.02	-0.84	-0.78
		.09	.08	.08	.03	.09	.11	.06	.09	.08
SD-c	12	-0.46	0.68	0.88		-			-	
		.15	.12	.15						
SD-d	6		-			-			-	

Table 3 (continued).

Type of systems	n	a_1	b_1	$k(RA)$	a_2	b_2	$k(RM)$	a_3	b_3	$k(Rq)$
SD	82	0.00	0.42	0.51	0.46	-0.22	-0.42	0.07	-0.73	-0.70
		.09	.08	.10	.02	.05	.10	.05	.08	.08
DS	11		-			-			-	
AR1	12		-			-			-	
AR2	12		-			-			-	
SD-a	6	-0.46	1.08	0.93		-			-	
		.15	.20	.18						
SD-b	58	-0.50	0.94	0.83	0.41	-0.54	-0.68	0.02	-0.84	-0.78
		.09	.08	.08	.03	.09	.11	.06	.09	.08
SD-c	12	-0.46	0.68	0.88		-			-	
		.15	.12	.15						
SD-d	6		-			-			-	
SD-1b	15		-		0.22	-0.33	-0.56		-	
					.03	.14	.23			
SD-2b	14		-		0.38	-0.39	-0.88	0.18	-0.48	-0.79
					.02	.06	.14	.05	.09	.18
SD-3b	14	1.20	-0.54	-0.60	0.53	-0.23	-0.89	0.35	-0.34	-0.74
		.24	.20	.23	.01	.03	.13	.06	.08	.20
SD-4b	15		-		0.63	-0.51	-0.88	0.28	-0.70	-0.85
					.03	.08	.13	.06	.08	.14

Table 4. Coefficient of correlation between temperature excesses $\Delta \lg T$ and $\Delta \lg R$ and $\lg A$, $\lg M$, $\lg g$ in the case when k is statistically significant. Standard deviations are also given. Dash means that significance level is negligible.

Type of systems	n	c_1	d_1	$k(TA)$	c_2	d_2	$k(TM)$	c_3	d_3	$k(Tq)$
SD	82		-		0.04	-0.25	-0.70	-0.25	-0.56	-0.80
					.01	.03	.08	.03	.05	.07
DS	11		-		-0.03	-0.54	-0.80		-	
					.03	.14	.20			
AR1	12		-			-			-	
AR2	12		-		-0.03	-0.33	-0.56		-	
					.02	.16	.26			
SD-a	6		-		-0.11	-0.62	-0.99	-0.20	-0.61	-0.95
					.02	.04	.07	.06	.09	.16
SD-b	58		-		-0.01	-0.47	-0.86	-0.25	-0.56	-0.74
					.01	.04	.07	.03	.05	.09
SD-c	12		-			-			-	
SD-d	6		-			-			-	
SD-1b	15		-		-0.03	-0.54	-0.81	-0.25	-0.67	-0.80
					.02	.11	.16	.05	.12	.16
SD-2b	14		-		-0.01	-0.42	-0.89	-0.23	-0.52	-0.76
					.02	.06	.13	.06	.10	.19
SD-3b	14		-		-0.01	-0.48	-0.86	-0.42	-0.77	-0.75
					.03	.08	.15	.11	.16	.19
SD-4b	15		-		-0.01	-0.46	-0.84	-0.34	-0.66	-0.87
					.03	.08	.15	.06	.08	.14