OBSERVED PROPERTIES OF CONTACT BINARY SYSTEMS

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ABSTRACT. A group of close eclipsing systems, which continues to pose a challenge in many subjects of modern astrophysics, is that of contact binaries. In this study, using the most recent observational data of a large sample of such systems, a review concerning their properties is presented. Except from the basic graphs, appeared so far in similar reviews, some new diagrams for their angular momentum, horizontal energy transfer, and corrected mass- radius relations are given. From them, some new important properties of contact binaries are derived.

Key words: Stars: binaries: contact

1. Introduction

Regardless the large number of papers referred to contact binaries -and especially to those of W UMa-type, that is to the late type ones- which have been presented up to now (e.g. Hazlehurst 1970, Mochnacki 1981, 1985, van Hamme 1982, Duerbeck 1984, Kaluzny 1985, Rucinski 1985, 1992, Maceroni et al. 1985, Kähler 1989, 1997, Rovithis-Livaniou et al. 1992, Maceroni, van't Veer 1996), a lot of problems, concerning their structure and evolution are still open. Lucy (1968) was the first to make serious attempt to construct equillibrium models of contact binaries that take into account Kuiper's paradox; and it had proved surprisingly difficult to construct contact systems, that satisfy all the observational constrains. Later, Biermann and Thomas (1972, 1973) proposed some models; while, various theories and other models were developed and suggested by many investigators concerning the structure and evolution of contact binaries, as well as their general properties (e.g. Vilhu 1973, Vilhu and Rahunen 1976, Hazlehurst 1976, Rahunen and Vilhu 1977, 1982, Shu 1980, Shu and Lubow 1981, Hazlehurst et al. 1973, 1980, 1982, 1984, Rahunen 1983, Smith 1984, Rucinski 1985, 1992, Webbink 1977, Rucinski and Kaluzny 1994, Karetnikov 1996).

Binnendijk (1970) divided the late type contact systems to two sub-classes: **A** and **W**, according to their light curves properties, while a third sub-class (known as E) was added to include the early type contact binary systems.

In the present study the properties of contact binaries will be presented, based on the latest observational data of a large sample of such systems. Special attention will be paid to the late type systems, since a larger number of them, compared to those of early type, have been observed and analyzed so far, and thus they yield to more reliable results.

2. Observational Data

The observational material used in the present study is mainly come from the photometric observations of these systems, and their subsequent analysis using modern techniques, based on the Roche geometry. Spectroscopic data were also used where available. Thus, eighty (**80**) contact binaries, with well observed light curves, were included in our study. From them, **38** belong to the **W** sub-class, **30** to **A**, and **12** are early type contact systems. The mass ratios range from $q = 1$ (for *V701 Sco*) to $q = 0.072$ (for *AW UMa*).

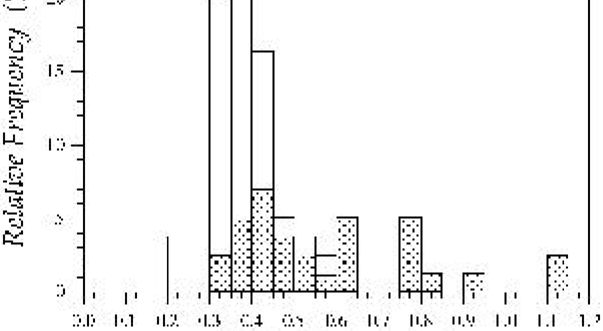

Figure 1: Orbital periods distribution of contact binaries.

3. General Observed Properties

3.1. Orbital Periods and Spectral Types

The orbital period distribution of contact binaries, in groups of 0.5 days, are presented in Fig.1, where dashed blocks denote the **A** sub-class systems, blanck these of **W**, and dashed-decline blocks those of **E**. The same symbolism will be kept in all other diagrams, where the relative frequency is involved. From this figure, one can notice that the periods of the **W** sub-class systems range from 0.22 to 0.65 days; these of the **A** are greater than 0.3, while those of **E** are greater than 0.8 days.

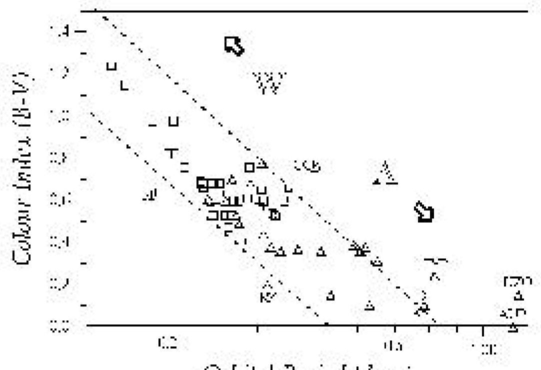

Figure 2: The period colour diagram of contact binaries.

Moreover, a relation exists between the colour index **(B-V)** and the orbital period **P**, known as the colour-period diagram, or Eggen's relation (Eggen 1961, 1967, Lucy 1968). For the sample used in our study, this relation is presented in Fig.2. Most of the contact systems lye within a zone -Eggen's zone- of 0.15 day width, with the **W** sub-class systems being at upper left part of the diagram, and the **A**, at right lower part; while, there is a mixing of the two sub-classes from F7 to G7 spectral types.

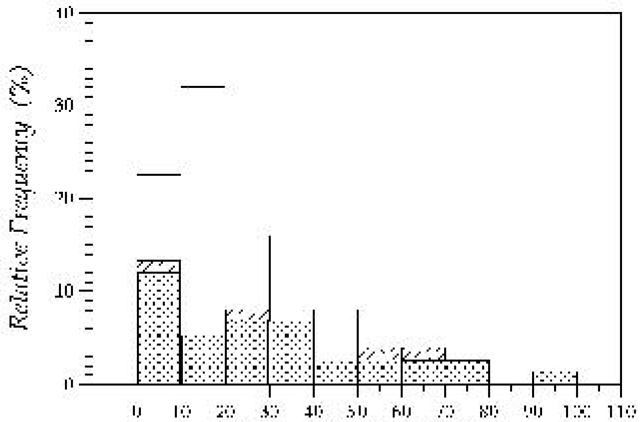

Figure 3: The filling factor distribution for contact binaries.

According to Hazlehurst (1970), the zone is extended in both sides of the line: $(B-V) = -0.55 - 2.26 logP$; while a different description is given by Kähler & Fehlberg (1991): $1.5 logT_{eff} - logP = c$, where c varies from 5.975 to 6.15.

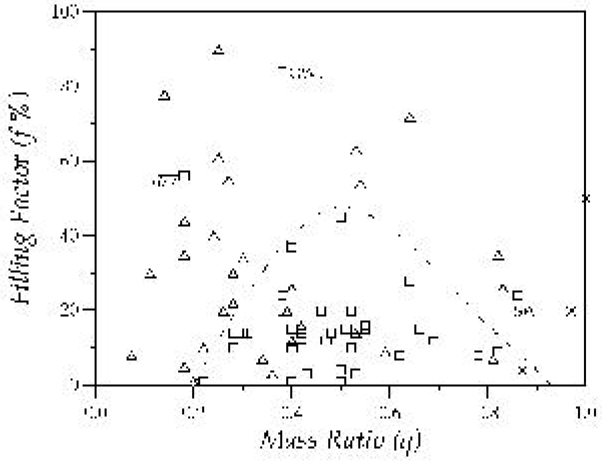

Figure 4: The filling factor mass-ratio relation of contact binaries. Squares denote the **W**, and triangles the **A** sub-class; while crosses the early type systems, **E**.

3.2. Mass-ratio and Filling Factor

Fig.3 presents the filling factor **f** (Mochnacki, 1981), distribution of contact systems.

All W UMa-type systems have small filling factors, generally less than 25%. More specifically, in most of the **W** sub-class, **f** is around 15%, and in most of the A's **f** is around 5%. It seems that there is no contact system to be in complete over-contact (having $f = 100\%$). The **f** values are less than 84%, with one exception, the *UZ Leo* system, for which **f** was found to be equal to 90%; but, the accuracy of its elements is not as high as that of other systems.

Fig.4, shows the filling factor mass-ratio relation, **f-q**, where squares denote the **W** sub-class systems, triangles these of **A**, and crosses those of **E**. This symbolism will be kept from here on. From Fig.4 one can notice that the **W** sub-class systems, with the exception of **3**, that is: of *SW Lac*, *V677 Cen* and *GW Cep*, are bounded by the dashed line.

From Fig.4, is also obvious that **W** systems, are getting greater filling factor values, when mass ratio q is around 0.5, and smaller for $q < 0.3$ & $q > 0.8$. On the contrary, the **A** sub-class systems are uniformly spread all over the **f-q** diagram, and appear to develope greater **f** values towards smaller mass-ratio **q**'s.

3.3. Masses and Radii

The masses of the late type contact binaries are generally small. The masses of their primary components are less than $2.4 M_{o}$, and these of their secondary stars less than $1.2 M_{o}$, M_{o} being the solar mass.

On the other hand, the radii of most of the primary stars of W UMa-type systems are very little above

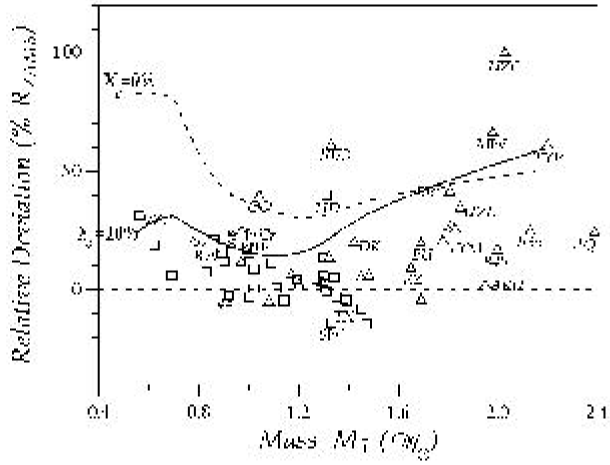

Figure 5: Relative deviation of primary stars radii of contact binaries, from ZAMS and TAMS. (Models by Mengel et al. 1979).

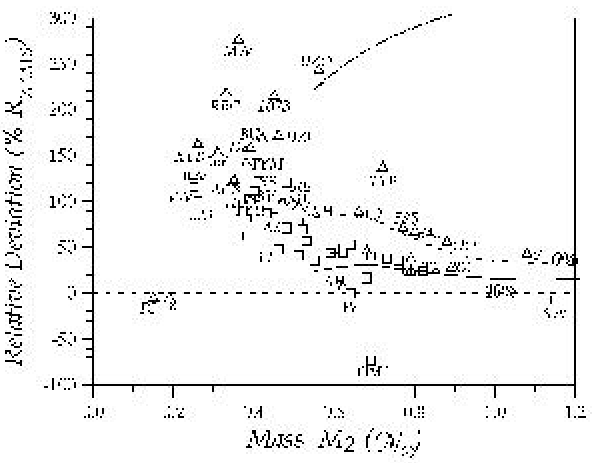

Figure 6: Same as Fig.5, but for the secondary components of contact systems. Moreover, the dashed-dot line denotes the radius value of an ordinary star, before endering the giant branch.

ZAMS (Fig.5); while, that of their secondaries are very much above it: from 30 to 300%, greater than ZAMS (Fig.6). It is worthwhile to mention that the relative deviation of the secondaries' radii is greater towards the smaller mass values.

In Figs.5 and 6, the thick dashed line denotes TAMS (when hydrogen in the star's nuclei is zero, 0%), while the continuous one stands for the luminosity of an ordinary star, when its hydrogen has been reduced to 10%. The same symbolism is used in Figs. 9, 10, 12 and 13, too.

3.4. Temperature Differences

The temperature difference appeared on the surface of the common photosphere of late type contact systems of W UMa-type, has been attributed to two absolutely different causes: 1) to the physical proccesses of their common envelope or 2) to the presence of dark spots, similar to those of our Sun. Assuming that the temperature differences are real, then from the light and colour curves analysis of these systems, it comes out that their values range from **-450** to **+550 K**, as is shown in Fig.7. From this figure, we notice that in the early type contact systems the temperature differences are very small (of the order of ±50 degrees).

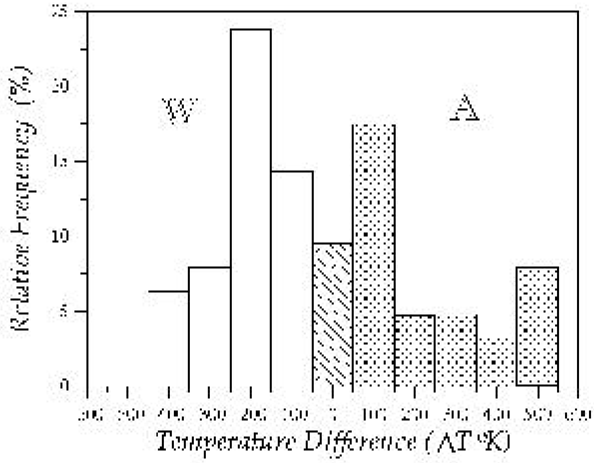

Figure 7: The temperature difference for the two basic sub-classes **W** and **A**, of contact binaries of W UMa-type.

Moreover, in Fig.8 the temperature difference versus the colour index (B-V) is shown. From this, is obvious that almost all W UMa-type systems with colour index greater than 0.5, (that corresponds to spectal types later than F7-8), have secondaries with much greater T_{eff} values than their primary components.

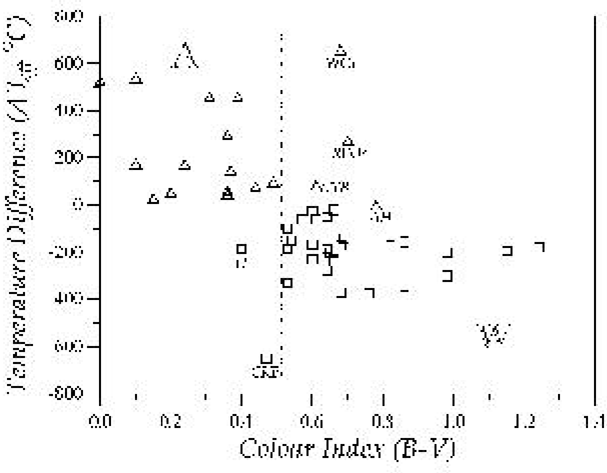

Figure 8: Relation between temperature differences and colour index (B-V), for the two basic sub-classes of contact binaries of W UMa-type.

3.5. Luminosities

The real luminosities of the two components of W UMa-type systems, can not be measured directly from observations, due to large amounts of energy transfer ΔL from primaries to the secondaries stars.

The total energy $L_1 + L_2$, coming out from the two components photospheres, is equal to the total energy $L_{1,c} + L_{2,c}$, produced by their nuclei, if the amount of energy lost by the primary is added to the secondary component. In Figs.9 and 10, the observed luminosities versus the ZAMS nuclear luminosities, for the primary and secondary stars of a contact binary are presented, respectively. The dashed diagonal line, denotes the relation $L_{1,ob} = L_{1,c}$, and $L_{2,ob} = L_{2,c}$, respectively, without energy transfer, and for zero age components. $L_{i,ob}$, i=1,2, stands for the observed luminosity of the two stars of the system.

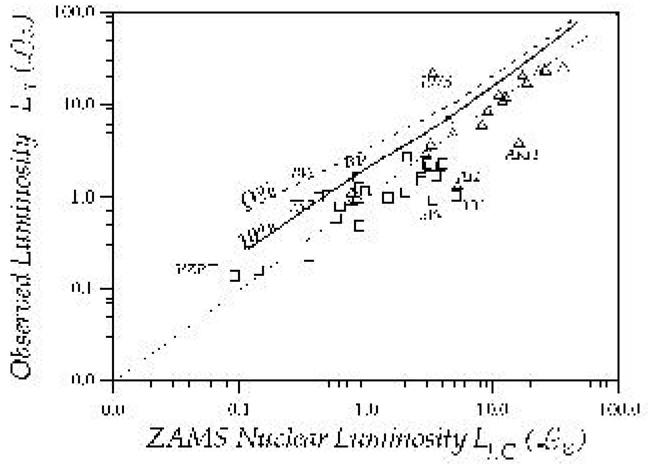

Figure 9: Comparison of the observed luminosity versus ZAMS nuclear luminosity for the primary components of late type contact binaries.

As is obvious from Fig.9, primary components follow in general the ZAMS mass-luminosity relation, although a large number is below it. On the other hand, Fig.10, shows 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.

4. The Energy Transfer

The energy transfer ΔL, is not a directly measured quantity. It can be computed, assuming that the energy lost by the primary star, is added to the secondary component to yield to an isothermal common photosphere. In such a case:
$L_{1,ob} = L_{1,c} - \Delta L$, and
$L_{2,ob} = L_{2,c} - \Delta L$.
Using *Stefan-Boltzmann*, and *Plank* laws, we get:
$((L_{1,c} - \Delta L)/(\sigma A_1))^{1/4} - ((L_{2,c} - \Delta L)/(\sigma A_2))^{1/4} = \Delta T_{eff}$, where A_i, i=1,2 is the area of the outer envelope of the i-component. This quantity can be arithmetically calculated through the Roche model, when the filling factor, the period and the two stars' masses are known. In this way ΔL was calculated and in Fig.11 has been plotted versus the mass-ratio q. Moreover, the following relation was found:
$log(\Delta L/L_{2,c}) = 2.66 - 3.5 \cdot q$
for the secondary components.

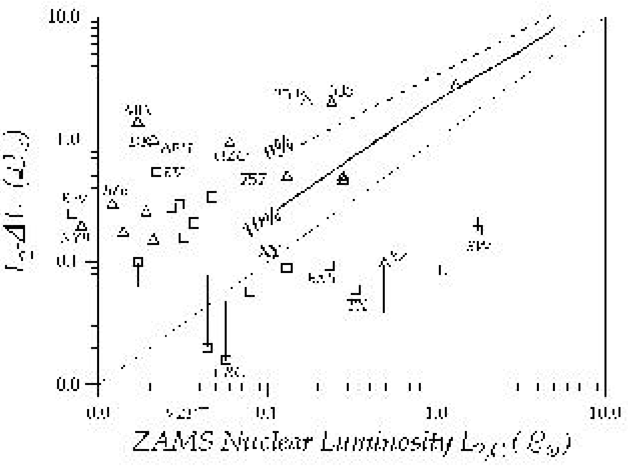

Figure 10: Same as Figure 9, but for the secondary components.

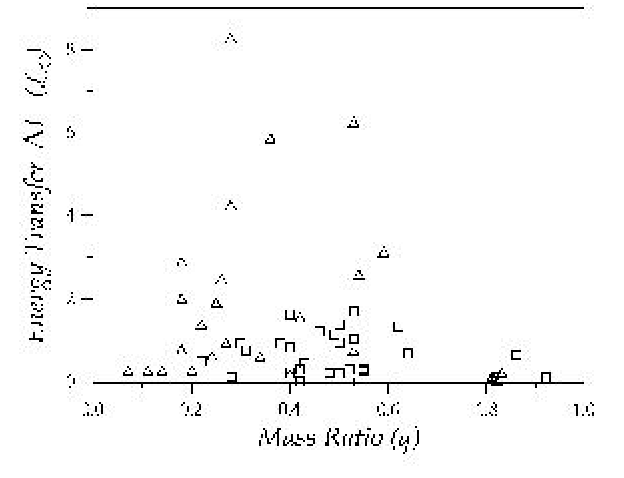

Figure 11: Energy transfer versus mass-ratio q, for the two basic sub-classes of contact binaries of W UMa-type.

A first estimation of the amounts of energy produced at the two stars' nuclei, is also possible since: $L_{1,c} = L_{1,ob} + \Delta L$ and $L_{2,c} = L_{2,ob} - \Delta L$, for the primary and the secondary components, respectively. Figs.12 and 13 present the corrected luminosities of primary and secondary components, respectively towards their ZAMS nuclear luminosities. Again, most primaries are very close to ZAMS, and with the exception of one (the *V1073 Cyg* system), no one is above TAMS. Five, (the *DK Cyg*, *U Peg*, *BV Dra*, *BW Dra*, and *VS Psc*) are on TAMS; while four, (the *SW Lac*, *YY Eri*, *AH Vir*, *AK Her*), are below ZAMS.

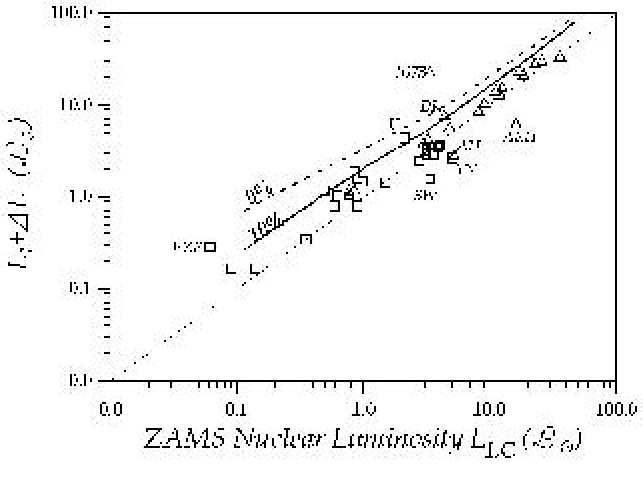

Figure 12: Comparison of the corrected luminosity towards ZAMS nuclear luminosity for primary components of the two basic sub-classes of late type contact binaries.

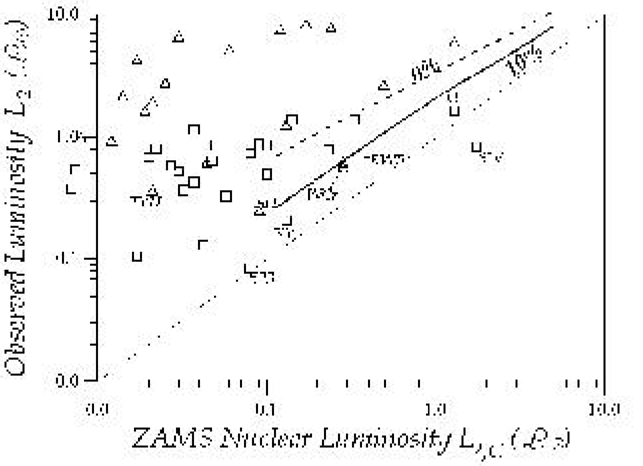

Figure 13: Same as figure 12, but for the secondary components.

On the contrary, a significant large number of secondaries (especially of the A sub-class), are on TAMS, or even above it. Due to big errors, this result is not certain; and although the whole picture can not be considered as clear, it seems that there are some weak indications according to which some of them (about 20%), is possible to be above ZAMS.

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