The evolution of low mass contact binaries

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Abstract. The present investigation is concentrated on low temperature contact binary systems of W UMa-type with orbital period shorter than 0.3 d. These systems appear to have some special properties, since none of them has extreme mass ratio (close to the value of 0.1 or less), they show cooler or heavily spotted primaries and the component masses and radii correspond to MS stars. Our models show that these systems originate from detached binaries with total mass lower than about 1.6 solar mass, in which the more massive component reaches the Roche lobe during its MS life. The approach to the Roche lobe overflow takes several Gyr. After mass ratio reversal a contact binary is formed with slow mass transfer to the presently higher mass component and angular momentum loss through the magnetized wind. Low rate of mass transfer together with the high AML results in coalescence of the binary after less than 1 Gyr spent in contact.

Introduction

The problem of origin and evolution of cool contact binaries is still far from full understanding. It is generally accepted that they originate from close but detached binaries which lose angular momentum (AM) through magnetized winds associated with the magnetic activity of cool stars. Due to proximity of the components they rotate synchronously with the orbital period so AM loss (AML) results in tightening of the orbit until the Roche lobe overflow (RLOF) by the more massive component occurs. We will identify the components of a contact binary as high mass component (HMC) and low mass component (LMC).

Evolution of such systems is still debatable. An old theory of Thermal Relaxation Oscillations (TRO), presented originally by Lucy (1976) and Flannery (1976), assumed that the small amount of matter transferred to the LMC makes it expand and fill its Roche lobe. The resulting configuration is in global thermal equilibrium but each component separately is not, and its size oscillates around the Roche lobe. The net mass transfer occurs on a secular time scale from the LMC to HMC until instability makes them to coalesce. The TRO theory encounters, however, several problems and some of its predictions are at odds with observations (Webbink 2003, Stępień 2011). However, a different theory has been suggested recently (Stępień 2006, 2009, Gazeas and Stępień 2008). It assumes that mass transfer following RLOF proceeds in a similar way as in classical Algols, i.e. until mass ratio reversal. After the rapid mass transfer, a contact configuration or, if too much AM is left in the system, a near contact binary is formed which, after some additional AML, reaches contact.

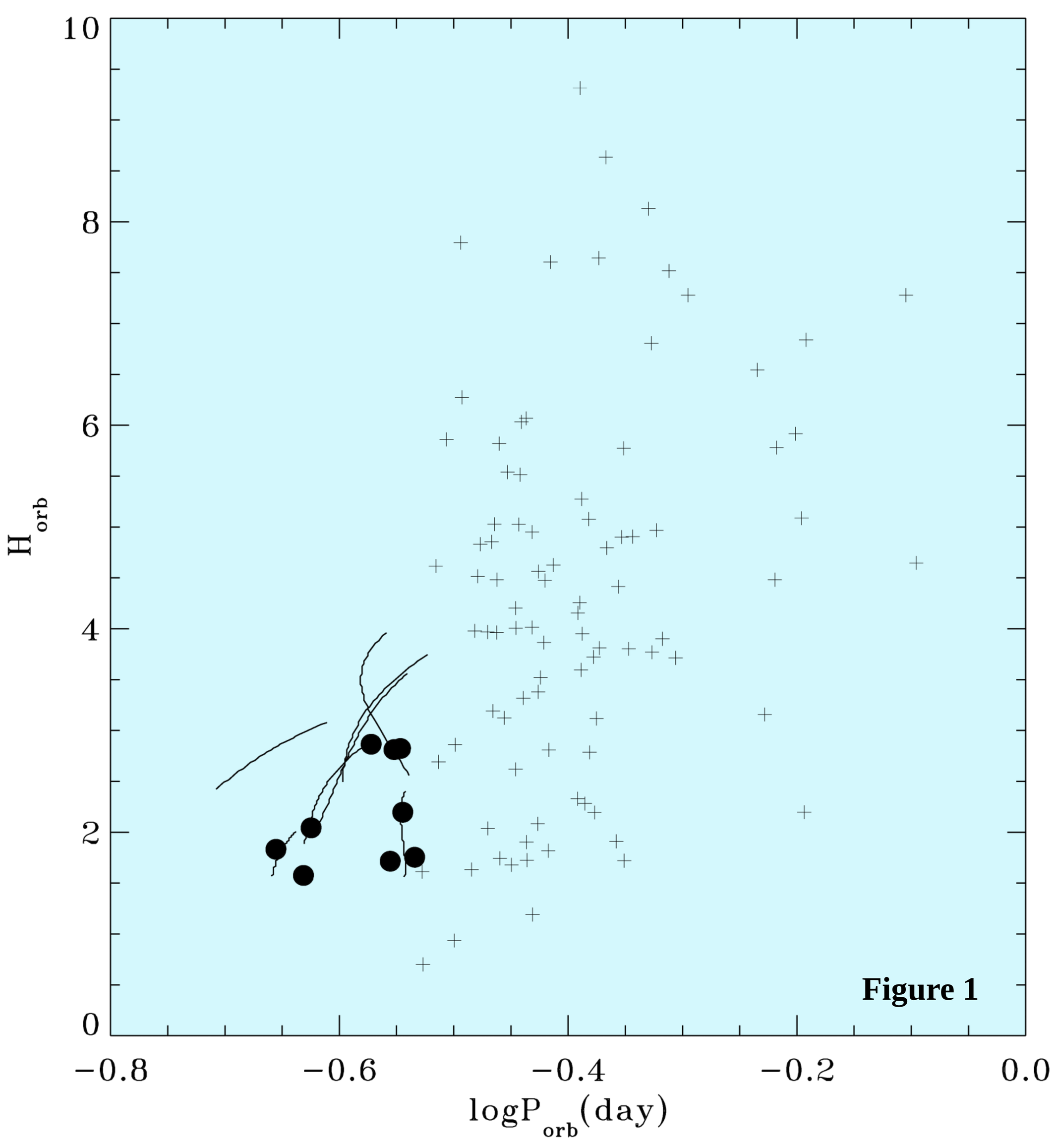
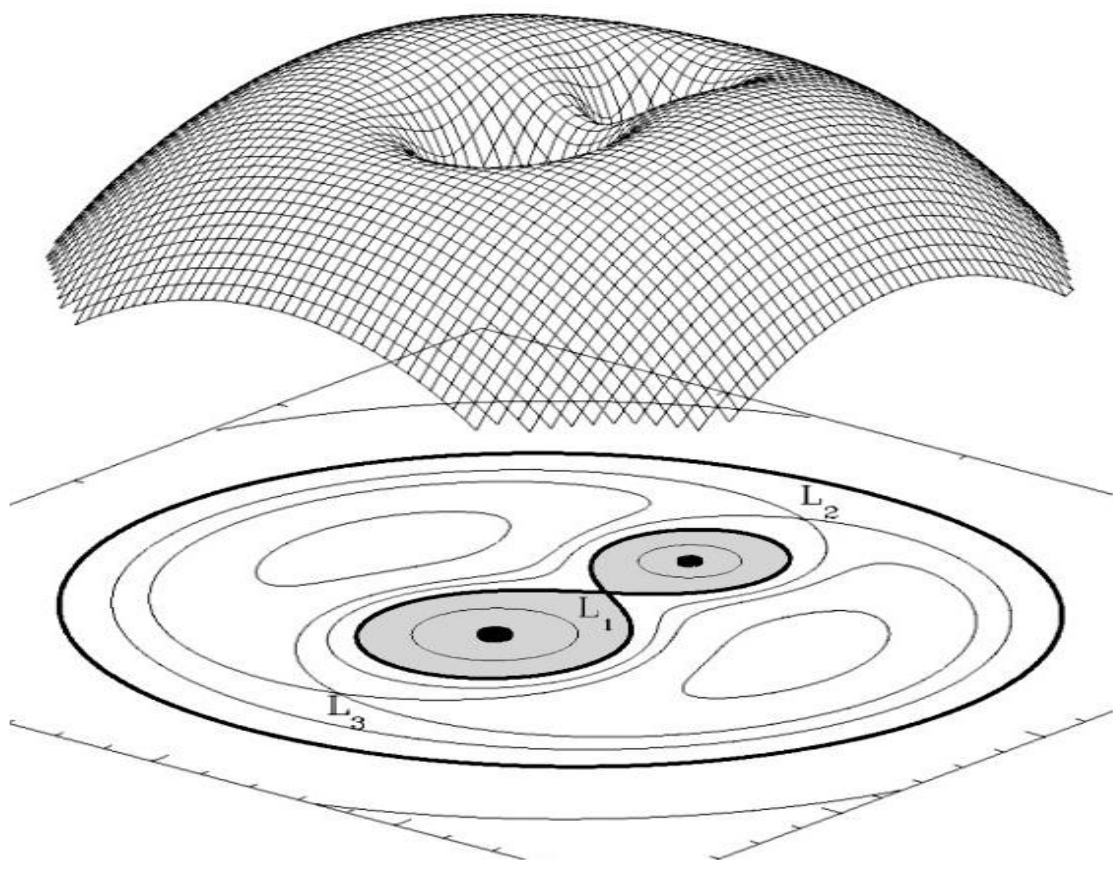


Figure 1



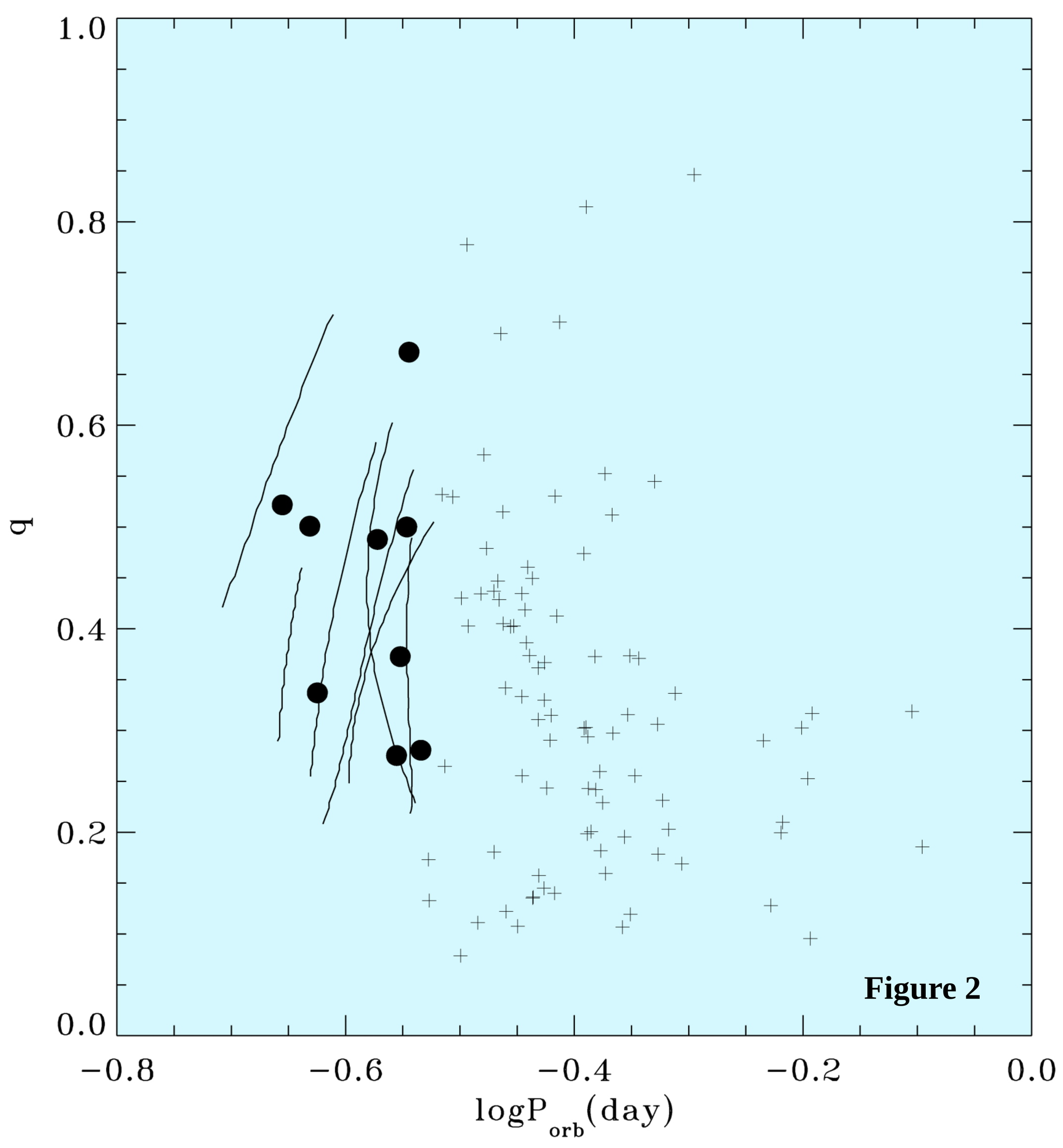


Figure 2

Figures 1-3 present the comparison of the computed models with the observations. **Figures 1 and 2** show, respectively, the orbital AM *versus* orbital period and the mass ratio *versus* orbital period of massive contact binaries of W UMa-type (crosses) and LMCB (filled circles), with the models overplotted (solid lines). Each line corresponds to the time evolution of one of the seven model binaries, from the time when the components reach contact till the point when they both overflow the outer critical surface, which results in their quick merging (Webbink 1977). The direction of evolution is from higher to lower values of H_{orb} in **Figure 1** and from higher to lower values of q in **Figure 2**. Separate component masses of W UMa-type stars are shown in **Figure 3** (below). In this case, crosses and triangles correspond, respectively, to HMC and LMC of massive contact binaries, whereas open and filled circles correspond to the same components of LMCB. As before, solid lines show the time evolution of the component masses of the model binaries. The direction of evolution is from higher to lower mass for the LMCs (they loose mass), while the opposite occur to the HMCs, since they gain weight after the mass transfer process. It is seen that the models describe observations very well, although **Figure 3** suggests that additional models with the total mass still lower than considered in the present investigation may better reproduce the observational data on the component masses.

The new model

The new model is based on the assumption that initial orbital periods of progenitors of cool contact binaries are close to a couple of days. It takes several Gyr until enough AM is lost and RLOF occurs. This time is sufficient to terminate the main sequence (MS) evolution by components with mass higher than 1 solar mass. After mass exchange the LMCs (former HMCs) of such binaries have hydrogen depleted cores. Their further evolution is determined by two main processes: AML by the wind and slow mass transfer from LMC to HMC resulting from the evolutionary expansion of the LMC.

Recently a new set of models of cool contact binaries was calculated by one of us (Stępień 2011). There are several models among them, which enter the contact phase when the orbital period is shorter than 0.3 days, i.e. they correspond to LMCB. The initial parameters of these models are: 0.9+0.3(2.5), 0.9+0.4(2.5), 0.9+0.5(2.0), 0.9+0.5(1.5), 0.9+0.7(2.0), 1.1+0.5(2.0) and 1.1+0.5(1.5), where the first two numbers give the initial component masses in solar mass and the number in parentheses gives the initial orbital period in days. It takes on average about 7 Gyr for each binary to reach the contact phase (less than that for binaries with HMC of 1.1 solar mass and more for binaries with HMC of 0.9 solar mass). Such systems live in a contact configuration for about 0.8 Gyr. After this phase, the orbital AM is so low (between 1.6 and 2.6×10^{51}) and the orbit so tight, that both stars overflow their outer critical surfaces. The binary loses rapidly mass and AM through the Lagrangian point L_2, which results in its coalescence. Note that both components are still on the MS although the LMC may be close to (or slightly beyond) the terminal age MS (TAMS) region. The mass ratio never reaches extreme values (close to 0.1 or less).

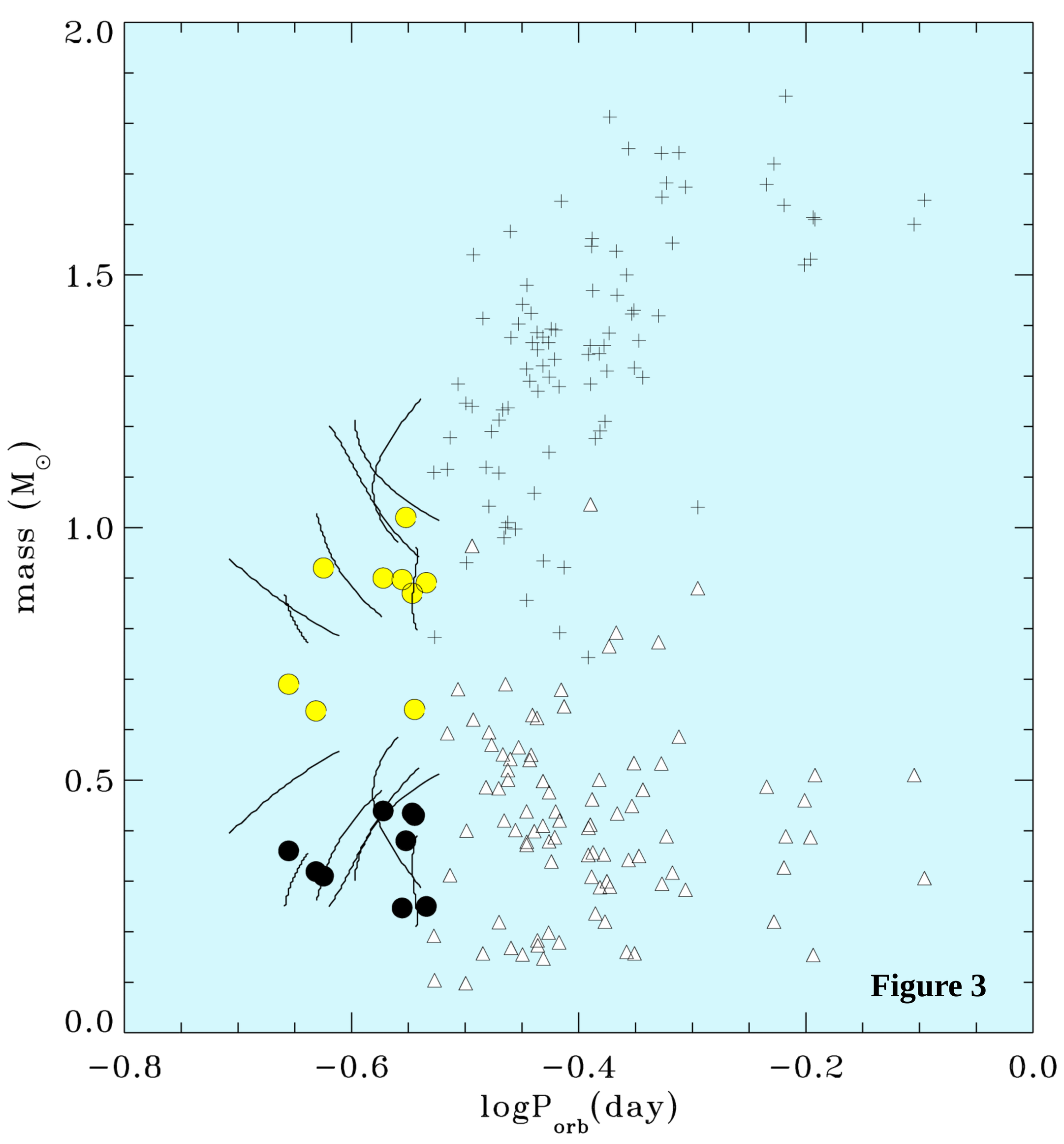


Figure 3

Comparison with observations

The observations of W UMa-type stars show that there is a number of low mass contact binaries (LMCB) with the total mass close to 1-1.4 solar mass (Gazeas & Niarchos 2006, Gazeas & Stępień 2008). Apart from low mass they have a few more unique properties, which make them deserve special attention. Their orbital periods are shorter than 0.3 days and their orbital AM is low (significantly less than 3×10^{51} in cgs units), while the component masses and radii indicate that they are both on the MS. All LMCB have cooler or heavily spotted primaries, which classifies them as W-type systems, according to the classification made by Binnendijk 1970. Based on this classification, light curves of W UMa-type stars belong to A-type or W-type variables, where the HMC of the A-type systems have larger average surface brightness than their companions, whereas the opposite occurs for W-type systems. The heavily covered surface of the HMC by cool spots is the most likely explanation for this effect, the so-called *W-phenomenon* (Stępień 1980, Eaton, Wu & Rucinski 1980, Zola et al. 2010). The relative spottiness depends on the magnetic activity of each component, which in turn depends on its mass, phase of the activity cycle etc. Many W UMa-type stars may change its type from W to A and *vice versa*. However, looking at the period-mass diagram of W UMa-type stars one can distinguish three period intervals: binaries with periods longer than 0.5 d are exclusively of A-type, binaries with periods between 0.5 and 0.3 d occur in both types and binaries with periods shorter than 0.3 d are exclusively of W-type (see Figs. 2 and 3 in Gazeas & Niarchos 2006). The purpose of the present paper is to explain the origin and evolution of LMCB. As observational data we took the first 9 stars from Table 1 of Gazeas & Stępień (2008), i.e. CC Com, V523 Cas, RW Com, 44 Boo, VW Cep, BX Peg, XY Leo, RW Dor and BW Dra. The updated parameters of CC Com, V523 Cas and XY Leo are taken from Zola et al. (2010).

Conclusions

It is suggested that W UMa-type stars with orbital periods shorter than about 0.3 d form a separate group of cool contact binaries (LMCB). They have total mass lower than about 1.4 solar mass, orbital AM less than about 3×10^{51} (in cgs units), radii corresponding to MS stars and mass ratio higher than about 0.2. None of them has an extreme mass ratio of the order of 0.1 and none of them is of A-type variable. According to our models they originate from detached binaries with total initial mass lower than 1.6 solar mass and initial orbital periods of 1.5-2 days. It takes several Gyr of evolution in the detached phase until RLOF occurs. Both components are still on the MS. After mass ratio reversal a contact binary is formed. Further evolution is driven mostly by AM loss via the magnetized wind which shrinks the orbit and makes both components overflow their outer Roche lobes. All LMCB are old, with a typical age of 7-8 Gyr although their contact phase lasts less than 1 Gyr, leading into coalescence.

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