

Violent stellar merger model for transient events

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ABSTRACT

We derive the constraints on the mass ratio for a binary system to merge in a violent process. We find that the secondary-to-primary stellar mass ratio should be $0.003 \lesssim (M_2/M_1) \lesssim 0.15$. A more massive secondary star will keep the primary stellar envelope in synchronized rotation with the orbital motion until merger occurs. This implies a very small relative velocity between the secondary star and the primary stellar envelope at the moment of merger, and therefore very weak shock waves, and low-flash luminosity. A too low-mass secondary will release small amount of energy, and will expel small amount of mass, which is unable to form an inflated envelope. It can, however, produce a quite luminous but short flash when colliding with a low-mass main-sequence star.

Violent and luminous mergers, which we term *mergebusts*, can be observed as V838 Monocerotis-type events, where a star undergoes a fast brightening lasting days to months, with a peak luminosity of up to $\sim 10^6 L_\odot$ followed by a slow decline at very low effective temperatures.

Key words: stars: individual: V838 Mon – stars: individual: V4332 Sgr – stars: individual: M31 RV – stars: mass-loss – stars: pre-main-sequence – supergiants.

1 INTRODUCTION

Stellar mergers have been recognized for a long time as events which can be important for evolution of binary systems. In discussions of globular clusters stellar mergers are usually considered as the most probable source of blue stragglers, e.g. De Marco et al. (2005, and earlier references therein; Sills, Adams & Davies 2005). In some cases, three or more stars might be involved (Knigge et al. 2006). However, the main interest in these cases has been directed towards understanding the nature of the final product of a merger in terms of its mass, chemical structure and farther evolution. Little attention, if any, has usually been paid to direct observational appearances of these events. This was obviously due to the common belief that the stellar mergers are very rare events and that, consequently, there is very little chance to observe them. However, the discovery of the eruption of V838 Mon in 2002 (Brown 2002) and subsequent studies of its observed evolution (Kimeswenger et al. 2002; Munari et al. 2002; Crause et al. 2003; Kipper et al. 2004; Tylenda 2005), as well as, of other similar objects, i.e. V4332 Sgr (Martini et al. 1999; Tylenda et al. 2005) and M31 RV (Mould et al. 1990) have led to suggestions that these observed events were likely to be due to stellar mergers (Soker & Tylenda 2003; Tylenda & Soker 2006, hereafter TS06). Likewise an analysis done by Bally & Zinnecker (2005) shows that stellar mergers in cores of young clusters, which

might be one of channels for producing very massive stars, can be source of luminous and spectacular observational events.

Different reasons can lead to stellar mergers. In dense stellar systems, as globular clusters or cores of young clusters, direct collisions of two stars or interactions of binaries with other cluster members can quite easily happen, often leading to a merger (for recent papers and more references see e.g. Lombardi et al. 2003; Fregeau et al. 2004; Mapelli et al. 2004; Dale & Davies 2006; for a review of these merger possibilities see Bailyn 1995). In multiple-star systems, dynamical interactions between the components or encounters between the system and other stars can destabilize stellar trajectories so that two components collide and merge. A binary stellar system can lose angular momentum during its evolution, e.g. due to mass loss, so the separation of the components decreases, which may finally lead to a merger. In the latter case, the merger is probably often relatively gentle and does not lead to spectacular events. This happens when the system reaches and keeps synchronization until the very merger. The relative velocity between the matter elements from different components is then very low, there is no violent shock heating and the orbital energy is released on a very long time-scale. However, when the binary component mass ratio is low the secondary is unable to maintain the primary in synchronization so the so-called Darwin instability sets in and the merger takes place with a large difference between the orbital velocity of the secondary and the rotational velocity of the primary. In this case the merger is expected to be violent, at least in the initial phase when the large velocity differences are dissipated in shocks. In this paper, we analyse

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this possibility in more detail and discuss observational appearances of violent mergers triggered by the Darwin instability in binaries.

We can schematically distinguish between three basic types of merger events. Of course, there is a continuous variation between the three types, but it is instructive to make these three ideal classes.

(1) The secondary is disrupted during the collision, and contributes most of the mass in the inflated envelope. This is likely to happen in a close to grazing collision with a not-too-compact companion in a very eccentric orbit. We suggest this type of merger as explanation for V838 Mon (TS06).

(2) Merger in a binary system which reaches merger in an unsynchronized rotation (the spin of the primary star is not synchronized with the orbital angular frequency), and where the secondary survives the initial merger stages. The secondary then spirals in inside the primary envelope. The inflated envelope comes mainly from the primary mass. The conditions for the occurrence of this type of merger are studied in this paper.

The above two merger types are expected to be violent. The third type is a non-violent merger.

(3) Merger between two stars having a synchronized rotation. The secondary is massive enough to maintain synchronized orbital motion until merger occurs. The secondary survives, and the two stars form a massive star in a relatively gentle process. Although this process is termed non-violent by us, it might still evolve on a dynamical time-scale at some phases, and it has many interesting properties. The spiralling-in process of the secondary deep inside the envelope will release a huge amount of orbital energy, which might result in a highly distorted mass-loss event (Morris & Podsiadlowski 2006). On a later time, the process can alter the evolution of the star on the Hertzsprung–Russell (HR) diagram (e.g. Podsiadlowski, Joss & Rappaport 1990). However, we do not expect a bright flash in these cases.

The gravitational and kinetic energy of the merging binary system can result in the following observational events.

(1) Flash of light. This flash is formed by emission from a strongly shocked gas, in the primary and/or secondary envelope, and will be observed as a flash lasting as long as the secondary is violently slowed-down in the outer regions of the primary star. This can be from a few times the dynamical time of the system up to a very long time, depending on the condition of the merging system. For the flash to be bright, the duration should be short, which implies a large relative velocity between the secondary and rotating primary envelope.

(2) Gravitational and kinetic energy of matter expelled to large distances, and even leaving the system. The matter that does not leave the system, falls back on a dynamical time-scale at its maximum distance, and when it becomes optically thick it contracts on its Kelvin–Helmholtz time-scale. The Kelvin–Helmholtz time-scale of the inflated envelope is much shorter than the Kelvin–Helmholtz time-scale of the primary star, due to the very high luminosity and the very low mass of the inflated envelope. The large energy in the inflated envelope and its relatively short contraction time implies that the energy deposited in the inflated envelope results in a bright phase of the merging system, lasting much longer than the initial flash.

(3) Gravitational energy of the expanding inner layers of the primary and/or secondary (even destroying the secondary). This will be largely so when the secondary penetrates the deep layers of the primary star. When the inner layers of the primary finally relax to equilibrium it will be on a very long Kelvin–Helmholtz time-scale.

To form a bright transient event only the first two energy channels are relevant. These two channels require violent interaction between the secondary and primary stars. In this paper, we study the conditions for a violent merger triggered by the Darwin instability in a binary system.

2 VIOLENT MERGER

We consider a binary system composed of a primary star having a mass M_1 and a radius R_1 , and a much lower mass secondary $M_2 \ll M_1$. As the system evolves the two stars can merge. The merging can be caused by the expansion of the primary as it evolves along the main sequence and beyond, or by losing orbital angular momentum via tidal interactions, or both. In evolved binary systems, the wind carries most of the angular momentum. Young binary systems can interact with remnants from the progenitor disc and cloud, or with a tertiary object in the system. We assume that the binary system reaches synchronization before merging. Then, as the ratio of orbital separation to primary radius decreases due to one of the processes listed above, the system becomes unstable to the Darwin instability and merges in a time-scale set by tidal interaction. This time-scale is shorter than the evolution time of the system. We now derive the conditions for this instability, and consider the consequences.

We make the following assumptions.

(1) A circular orbit. An eccentric orbit will yield a somewhat more violent merger, as the periastron orbital speed is higher than the Keplerian velocity at the same radius.

(2) The system reaches synchronization (corotation). Namely, the orbital angular velocity is equal to the primary's spin angular velocity.

(3) After the Darwin instability starts, the spiralling in process is relatively fast, such that no angular momentum is lost from the system. In reality, some angular momentum will be lost, slowing down the primary's angular rotation (spin).

(4) The primary rotation profile is that of a solid body. In reality, the tidal interaction will spin more the outer regions, implying higher primary angular velocity.

(5) The primary star maintains its spherical structure. In reality the primary equatorial radius will increase, slowing down its rotation.

The Darwin (Darwin 1887) instability occurs when the secondary star cannot maintain anymore the primary in synchronization. Namely, as the secondary spirals in, e.g. because of tidal interaction, the orbital angular velocity is higher than the primary's rotation angular velocity. The condition for the instability is (e.g. Eggleton & Kiseleva-Eggleton 2001) $I_{\text{orb}} < 3I_1$, where I_{orb} is the moment of inertia of the binary system, and $I_1 = \eta M_1 R_1^2$ is the moment of inertia of the primary; $\eta \simeq 0.05$ for the main-sequence stars of $M_1 \simeq 3 M_\odot$ and only weakly depends on the stellar mass (Meynet et al. 2006). Substituting $M_2 \ll M_1$ in the expression for the orbital moment of inertia, gives the orbital separation a_c below which the Darwin instability exists

$$\frac{a_c}{R_1} = \left(\frac{3\eta}{q} \right)^{1/2} = 2.2 \left(\frac{\eta}{0.05} \right)^{1/2} \left(\frac{q}{0.03} \right)^{-1/2}, \quad (1)$$

where $q = M_2/M_1$. The value of a_c/R_1 as a function of q and for $\eta = 0.05$ is drawn on the upper panel of Fig. 1.

Under the assumption of a circular orbit, the secondary star enters the primary's envelope with an orbital velocity v_{orb} and angular

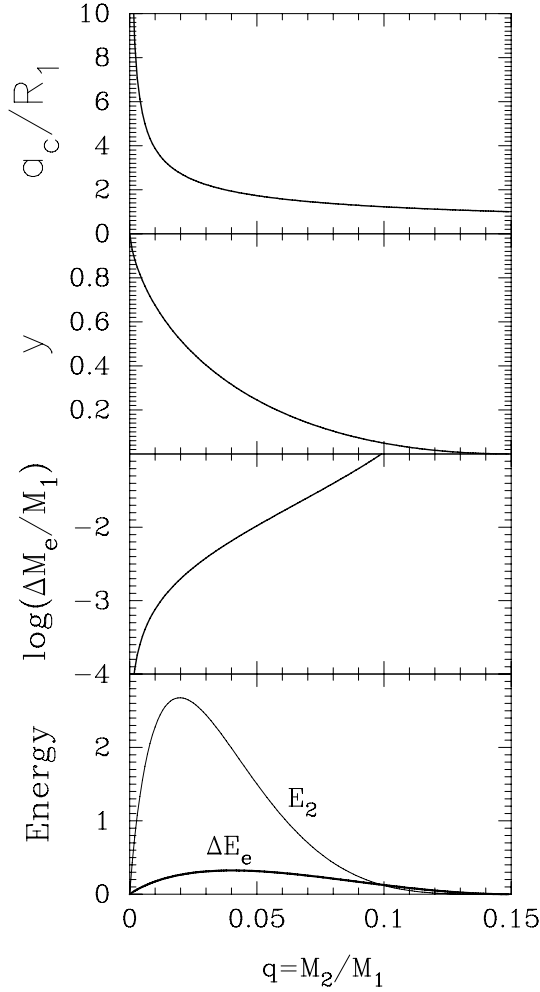


Figure 1. Some quantities as a function of the mass ratio, q , for $\eta = 0.05$. Upper panel: the orbital separation a_c , in units of the primary radius R_1 , at which the Darwin instability starts (equation 1). Second panel: the relative velocity between the secondary and envelope as merger starts, in units of v_{orb} (equation 4). Third panel: the mass that is disturbed at the very outer part of the envelope, as given by equation (6) with $f = 0.9$ and in units of M_1 . Lower panel: the secondary kinetic energy (equation 5) depicted with a thin line, while the energy deposited in the very outer part of the envelope, $\Delta R = 0.1R_1$ (equation 7), is drawn with a thick line. Energies are in units of $10^{-3} GM_1^2/R_1$.

velocity ω_{orb} that are given by

$$v_{\text{orb}} = \omega_{\text{orb}} R_1 = \left(\frac{GM_1}{R_1} \right)^{1/2}. \quad (2)$$

The primary's angular velocity ω_1 and surface equatorial velocity v_1 during merger are derived from angular momentum conservation. Namely, the orbital angular momentum released by the secondary as it spirals in from $a = a_c$ to R_1 equals the change in the primary's angular momentum. Under the assumptions listed above, we derive

$$\frac{\omega_1(\text{merge})}{\omega_{\text{orb}}} = 4 \left(\frac{R_1}{a_c} \right)^{3/2} - 3 \left(\frac{R_1}{a_c} \right)^2. \quad (3)$$

The orbital velocity of the secondary relative to the rotating primary envelope as merger starts is

$$y \equiv \frac{(v_{\text{orb}} - v_1)}{v_{\text{orb}}} = \left[1 - 4 \left(\frac{R_1}{a_c} \right)^{3/2} + 3 \left(\frac{R_1}{a_c} \right)^2 \right]. \quad (4)$$

The value of y as a function of q is drawn in the second panel of Fig. 1.

We can build several other interesting quantities. First, we can derive the secondary kinetic energy relative to the rotating primary envelope

$$E_2 = \frac{1}{2} M_2 (v_{\text{orb}} - v_1)^2 = \frac{1}{2} \frac{GM_1^2}{R_1} q y^2. \quad (5)$$

This is plotted by the thin line in the lower panel of Fig. 1. The energy is given in units of $10^{-3} GM_1^2/R_1 = 3.8 \times 10^{45} (M_1/M_\odot)^2 (R_1/R_\odot)^{-1}$ erg.

We are interested in the violent interaction of the secondary with the primary envelope during merger. A rather compact secondary (low-mass main-sequence star, brown dwarf) can penetrate quite deeply into the envelope. In this case, most of the event would result in observational effects on a rather long thermal scale. Also, when energy is deposited well inside the envelope, most of the energy is channelled to uplift outer envelope layers, causing only a small observational signature. However, even in a case like this the initial interaction in the outer envelope is expected to give violent dynamical effects. Therefore, we are looking at the interaction, when the secondary spirals a distance ΔR in from $a = R_1$ to fR_1 , where $1 - f = (\Delta R/R_1) \ll 1$. Let the secondary transfers the angular momentum to an envelope mass ΔM_e as it spirals in. The amount of angular momentum transferred to this mass is $\Delta J_e \simeq \Delta M_e (v_{\text{orb}} - v_1) R_1$, while the angular momentum lost by the secondary is $\Delta J_2 \simeq M_2 (GM_1 R_1)^{1/2} (1 - f^{1/2})$. Conservation of angular momentum then gives

$$\Delta M_e \simeq (1 - f^{1/2}) y^{-1} M_2 \simeq \frac{\Delta R}{2R_1} y^{-1} M_2. \quad (6)$$

This mass is actually the mass that was strongly shocked and is free to expand with almost no disturbances. A large fraction of this mass is expected to be expelled from the system and/or to form an extended envelope due to its large entropy. The value of ΔM_e as function of q , in units of M_1 and for $f = 0.9$, is given in the third panel of Fig. 1. Its derivation assumes local interaction of the secondary star with the primary envelope, and therefore it is applicable only to low-mass secondary stars, $q < 0.1$; for more massive secondary stars the value of ΔM_e as given above requires non-local interaction.

The energy carried by the mass ΔM_e is

$$\Delta E_e \simeq \frac{1}{2} \Delta M_e (v_{\text{orb}} - v_1)^2 = \frac{1 - f^{1/2}}{2} \frac{GM_1^2}{R_1} q y \simeq \frac{\Delta R}{4R_1} \frac{GM_1^2}{R_1} q y. \quad (7)$$

This is plotted for $\Delta R = 0.1R_1$ by the thick line in the lower panel of Fig. 1; the energy is given in units of $10^{-3} GM_1^2/R_1$. This energy is actually the energy residing in gas with high entropy that is expected to be expelled and/or form the extended post-merger envelope.

From the results plotted in Fig. 1 alone, we can deduce that for an efficient eruptive (violent) merger the mass ratio should be in the range $0.003 \lesssim q \lesssim 0.1$. Massive companions can liberate a huge amount of energy as they merge. However, because the synchronization is kept till the merger, the process is less violent. The system will not be observed as a violent luminous transient event. Low-mass companions ($q \lesssim 0.003$) release little energy resulting in a rather weak event, although in some cases (see next section) they can give rise to short but luminous bursts.

We can estimate the rate at which the energy is released during the violent phase of the merger and the time-scale of this event. To do so, we have to estimate an effective interaction radius, R_{eff} , of the secondary spiralling inside the primary's envelope. One can do this in an analogous manner as defining the Bondi–Hoyle accretion

radius. In our case, the primary's matter moving relative to the secondary is in the gravitational potential of the primary, so we define R_{acc} as satisfying

$$\frac{GM_2}{R_{\text{acc}}} \simeq \frac{1}{2}(v_{\text{orb}} - v_1)^2 + \frac{GM_1}{R_1} = \frac{GM_1}{R_1} \left(\frac{1}{2}y^2 + 1 \right). \quad (8)$$

The term $(1/2)y^2$ is never greater than 0.5, so we can neglect it in a first approximation, and obtain

$$R_{\text{acc}} \simeq qR_1. \quad (9)$$

In a number of cases, e.g. a brown dwarf merging with a solar-type star, equation (9) predicts R_{acc} lower than the radius of the secondary, R_2 . In a case like this, it seems to be more reasonable to adopt $R_{\text{eff}} = R_2$ instead of $R_{\text{eff}} = R_{\text{acc}}$. For a general purpose, we therefore adopt

$$R_{\text{eff}} = \xi R_1, \quad (10)$$

where

$$\xi = \max \left(q, \frac{R_2}{R_1} \right). \quad (11)$$

The rate of the energy dissipation, L_{diss} , can be estimated from

$$L_{\text{diss}} \simeq \frac{1}{2} \pi R_{\text{eff}}^2 \rho_1 (v_{\text{orb}} - v_1)^3 = \frac{1}{2} \pi \xi^2 y^3 (GM_1)^{3/2} R_1^{1/2} \rho_1, \quad (12)$$

where ρ_1 is the density in the primary's envelope. Note that if a significant part of the dissipated energy goes for producing an inflated envelope (as discussed below) and/or for mass loss, then the radiation luminosity will be significantly lower than the above estimate of L_{diss} .

The time-scale of the violent merger can be estimated from

$$\tau \simeq \frac{\Delta E_e}{L_{\text{diss}}} \simeq \frac{(1 - f^{1/2}) M_1^{1/2} q}{\pi G^{1/2} R_1^{3/2} y^2 \xi^2 \rho_1}. \quad (13)$$

Note that equation (13) estimates the time-scale of the initial violent phase when the shocked matter can easily escape from below the primary's surface and become observable. The total merger can last significantly longer depending on how deep the secondary can penetrate before being disrupted and how much time the energy released during the final phases would require to diffuse to the photosphere.

A significant part of the energy liberated during the merger event can go to produce an inflated envelope. To estimate the radius of the envelope, R_{ie} , we follow TS06. The envelope is taken to be a $n = 3$ polytropic gas (Tylenda 2005) sitting on the top of the merger product in a quasi-hydrostatic equilibrium, and with a total mass $M_{\text{ie}} = \beta \Delta M_e$. The gravitational energy of the inflated envelope is (TS06)

$$E_{\text{ie}} \simeq - \frac{GM_1 \beta \Delta M_e}{2R_1} \frac{1}{\ln(R_{\text{ie}}/R_1)}. \quad (14)$$

The energy of this mass prior to merger was

$$E_{\text{ie0}} \simeq \frac{GM_1 \beta \Delta M_e}{R_1} \left[-1 + \frac{(1 - y)^2}{2} \right]. \quad (15)$$

We assume that most of the orbital energy liberated as the secondary spirals in from $a = R_1$ to fR_1 goes to inflate the envelope. Therefore, the difference in the energy of the inflated mass before and after the merger is about equal to the energy liberated by the spiralling-in secondary star

$$E_{\text{ie}} - E_{\text{ie0}} \simeq \frac{GM_1 M_2}{2R_1} \left(\frac{1}{f} - 1 \right). \quad (16)$$

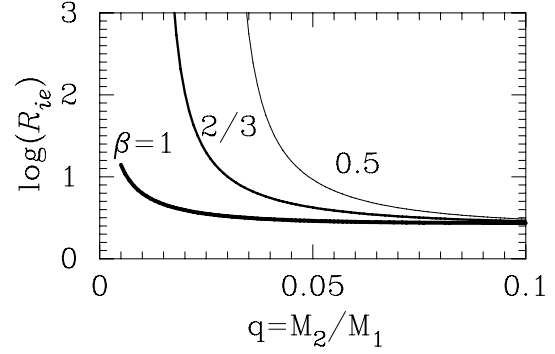


Figure 2. Logarithm of the radius of the inflated envelope in units of R_1 , as given by equation (17) or (18). β is the mass in the inflated envelope in units of ΔM_e (see equation 6).

Equations (14)–(16) can be solved to read

$$\ln \frac{R_{\text{ie}}}{R_1} \simeq \left[2 - (1 - y)^2 - \frac{M_2}{\beta \Delta M_e} \left(\frac{1}{f} - 1 \right) \right]^{-1}. \quad (17)$$

We use equation (6) to substitute for $M_2/\Delta M_e$, take $f = 1 - (\Delta R/R_1)$ with $\Delta R \ll R_1$, and neglect high order in $\Delta R/R_1$. We derive

$$\ln \frac{R_{\text{ie}}}{R_1} \simeq \left[1 - 2y \left(\frac{1}{\beta} - 1 \right) - y^2 \right]^{-1}. \quad (18)$$

Equation (18) is a crude estimate of the radius of the inflated envelope. From Fig. 2, we can see that if a fraction $\beta \lesssim 0.7$ (depending on q) of the shocked mass ΔM_e is ejected to the inflated envelope, then a radius of $R_{\text{ie}} \sim \text{few} \times 100 R_1$ can be achieved (as long as the fraction is not too low).

3 THE PRIMARY STAR

A violent merger induced by the Darwin instability can occur if the mass ratio $q \lesssim 0.1$ (see e.g. Fig. 1). Details of the event, e.g. luminosity and time-scale, depend on the masses and structures of the merging components. To show this let us consider three cases, in which the primary, i.e. more massive of the merging companions, is a 1- M_\odot main-sequence star (case 1), an 8- M_\odot main-sequence star (case 2) and a 3- M_\odot red giant (case 3).

In case 1 $q \lesssim 0.1$ means that the secondary is a very low-mass star, a brown dwarf or a massive planet. In all these cases, the radius of the secondary is $R_2 \simeq 0.1 R_\odot$. This is greater than R_{acc} defined by equation (9) so we assume $\xi \simeq 0.1$. We can also take $\rho_1 = 3 \times 10^{-3} \text{ g cm}^{-3}$ as a typical density at $0.95\text{--}0.90 R_1$.

The main-sequence lifetime of an 8- M_\odot star is $\sim 3 \times 10^7 \text{ yr}$. This is shorter than the pre-main-sequence lifetime of a secondary $< 1 M_\odot$. Using equation (A4) in TS06, we obtained, for an age of $1 \times 10^7 \text{ yr}$, $R_2 \simeq 0.7 (q/0.03)^{2/3} R_\odot$. For $q < 0.1$ this is larger than R_{acc} , so in case 2, assuming $R_1 = 5 R_\odot$, we can take $\xi \simeq 0.14 (q/0.03)^{2/3}$. As the density in the primary envelope we assume $\rho_1 = 3 \times 10^{-5} \text{ g cm}^{-3}$.

As parameters of the red giant primary in case 3 we take $M_1 = 3 M_\odot$, $R_1 = 30 R_\odot$ and $\rho_1 = 5 \times 10^{-6} \text{ g cm}^{-3}$. Down to $q \simeq 0.003$ the radius of the secondary is smaller than R_{acc} (equation 9), so we take $\xi \simeq q$.

Results of substituting the above parameters to equations (12) and (13) are shown in Fig. 3. In all the cases, $f = 0.9$ has been assumed in equation (13). The above-described cases 1, 2 and 3 are presented with full thick, full thin and dashed curves, respectively.

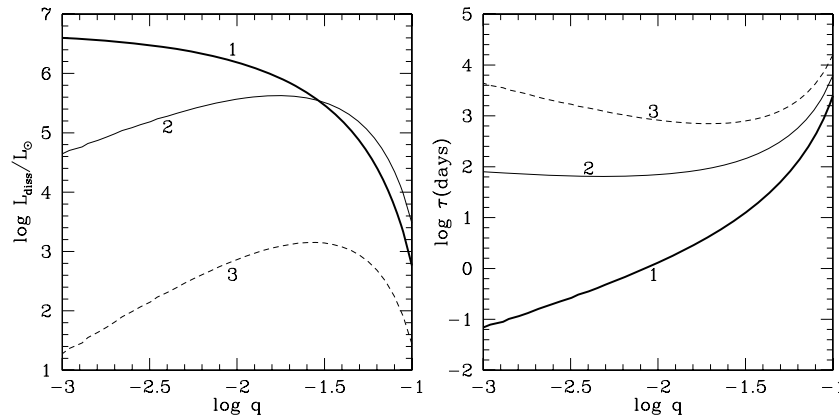


Figure 3. The dissipated luminosity (left-hand panel) and the time-scale (right-hand panel) of the violent merger as a function of the mass ratio, q , for three cases of the primary star, as described in the text. Full thick curves: case 1 (1 - M_{\odot} main sequence). Full thin curves: case 2 (8 - M_{\odot} main sequence). Dashed curves: case 3 (3 - M_{\odot} red giant).

As can be seen from Fig. 3 the mergers with the main sequence stars are more energetic, in terms of the dissipated luminosity, as those with a red giant. This is due to lower densities in the giant envelope and larger radii, hence lower velocity differences, at which the energy dissipation takes place.

In the case of a solar-type star, the merger with a low-mass object gives rise in luminosity up to $\sim 10^6 L_{\odot}$ but on a short time-scale. In the case of a Jupiter-like planet, this would be a burst as short as an hour. The burst would, however, be followed by a decline on a much longer time-scale.

The case of the 8 - M_{\odot} main-sequence star is relevant to the outburst of V838 Mon (TS06). For a mass ratio $q \simeq 0.03$ Fig. 3 predicts a luminosity of a few times $10^5 L_{\odot}$ on a time-scale of a 100 d, which is in a reasonable agreement with the observations (see e.g. Tyndala 2005). Note, however, that in order to get a better agreement with the observations TS06 propose that the merger in V838 Mon occurred from a highly eccentric orbit.

In the case of a red giant star, the merger event is relatively mild. It can raise the stellar luminosity by a factor of a few only but on a time-scale as long as several years.

4 DISCUSSION

In Section 1, we distinguish between three basic types of merger events. (1) A violent event, where the secondary is disrupted and supplies most of the ejected and inflated envelope mass. This occurs when the secondary star is loosely bound, e.g. a pre-main-sequence star, and there is a grazing (rather than a head-on) collision from an eccentric orbit. (2) A violent merger, where the secondary survives to a deeper depth in the primary envelope, and most of the inflated envelope originates in the very outer layers of the primary stellar envelope. Such a merger is likely to occur in a binary system when the secondary cannot maintain the primary envelope in synchronization (corotation) with the orbital motion. (3) A non-violent merger, occurring when the secondary maintains synchronization until merger occurs.

The basic results of this paper are that the type-2 merger defined above can cause a very bright event when the primary is a main-sequence star. The peak luminosity can reach $L_{\text{peak}} \gtrsim 10^5 L_{\odot}$, and last up to a few months. Our claim might seem somewhat contrary to intuition, as one might expect the merger event to become more violent as the secondary mass increases. However, as the secondary

stellar mass increases, the relative velocity between the secondary star and the primary stellar envelope at the moment of merger decreases, implying weaker shock waves in the very outer layers of the envelope.

Interestingly, we find that the type-2 merger can lead to a merger event similar to that observed in V838 Mon, although type-1 event seems to fit observations a little better (TS06; Soker & Tyndala 2007). The hugely inflated envelope in the type-1 merger event discussed by TS06 for V838 Mon, must have both a grazing collision and a pre-main-sequence secondary star. These ingredients are not required in the type-2 merger scenario. However, the type-2 merger scenario cannot lead to a massive inflated envelope. The total mass in the expelled shell and in the inflated envelope of V838 Mon is $M \simeq 0.1\text{--}0.3 M_{\odot}$ (Tyndala 2005; Soker & Tyndala 2007). This mass favours the type-1 merger for V838 Mon. However, if this mass will turn out to be $M \lesssim 0.05 M_{\odot}$ the type-2 merger model might work as well.

One of the important observational aspects of the merger events is the decline phase. Mass loss from a merger is always much smaller than the mass disturbed in the event. Most of this disturbed matter will form a more or less inflated envelope of the primary. When the merger processes dissipating energy are over the only source of luminosity in the envelope is the gravitational energy released in its contraction. However, the thermal time-scale of the envelope is comparable to or lower than its dynamical time-scale, especially if the envelope outer radius is much larger than the thermal equilibrium radius of the primary. Therefore, the envelope contraction phase will be preceded by a rapid cooling of the envelope outer layers. This cooling can go down to the Hayashi limit. Therefore, the merger remnant is expected to decline as a very cool star. This is the main observational aspect allowing to distinguish the merger events from thermonuclear runaway events, e.g. nova-type outbursts. In the latter case, as it is well known from theoretical models and observations, the object has to evolve to very high effective temperatures ($\gtrsim 10^5$ K) before the final decline.

The exact evolution of the merger remnant as it re-establishes equilibrium requires numerical calculations. Podsiadlowski (2003) has considered an instantaneous removal of mass from a subgiant, together with an instantaneous addition of energy to its remaining envelope. When the heating is sufficiently high, in a short time the star reaches high luminosity, and then it contracts more or less along the Hayashi line. However, when a mass is removed and the heating

(energy addition) is not sufficient, the star becomes very underluminous (Podsiadlowski 2003). The less-heated star starts its life to the left of the Hayashi line on the HR diagram, and then contracts and fades, but as a less-luminous and smaller star than a star of the same parameters on the Hayashi line. The reason is that after mass is instantaneously removed from the outer layers of the envelope deep layers have to expand outward. This requires a lot of energy. In the merger process, mass is added and lots of orbital energy is released. Thus, there is no need for the inner envelope's layers to expand. On the contrary, after the short outburst which makes the star luminous and inflates an envelope, layers in the extended envelope have to contract. We therefore expect the merger remnant to decline along the Hayashi line. A behaviour like this was observed during the eruption and subsequent decline of V838 Mon (Tytenda 2005).

Soker & Tytenda (2007) suggest to call the violent merger events *mergebust*. As it is clear from this study, these events can be easily observable not only in our Galaxy but also beyond it. What is the galactic *mergebust* rate? We can crudely estimate it as follows. We use the estimated formation rate of blue stragglers as done by Ciardullo et al. (2005) to explain bright planetary nebulae in elliptical galaxies. Ciardullo et al. (2005) argued that blue stragglers can account for the formation of bright planetary nebulae in elliptical galaxies with an old stellar population, and estimated the blue stragglers formation rate per solar luminosity in galaxies. Their estimates yield a galactic blue stragglers formation rate of $\sim 0.1 \text{ yr}^{-1}$. The blue stragglers in their scenario require that the secondary mass be close to that of the primary, $0.7 M_1 \lesssim M_2 < M_1$, whereas in our scenario $0.003 M_1 \lesssim M_2 \lesssim 0.15 M_1$. Because the allowed range in M_2 is smaller in our proposed model, and the mass ratio is much smaller, we expect the type-2 *mergebust* rate to be less frequent, say $0.01\text{--}0.05 \text{ yr}^{-1}$. On the other hand, the merger rate of young systems due to perturbation from the environment, as proposed for V838 Mon (TS06), can add to the number of bright transient *mergebust* events. Over all, we estimate that bright transient *mergebust* events, resulting from stellar merger, will occur in the galaxy once every $\sim 10\text{--}50 \text{ yr}$.

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