The distance variation due to mass transfer and mass loss in (13.6+8) M and (13+10) M binary star systems

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Abstract

In this research the change in the distance of the two stars in two binary star systems (13.6+8)M and (13+10)M was studied, through the calculations the value $\dot{M}$ (rate of mass transfer) of the two phases of dynamical stages of mass which are mass loss and mass transfer has been extracted in its own way ,by extracting the value of $\dot{M}$ the value of $\dot{a}$(the distance variation between the two stars) has been found only in the mass transfer stage by using mathematical model ,in mass loss stage $\dot{M}$ and $\dot{a}$ were calculated from the change and the difference between the values of each at different times of binary star system evolution ,it was found that the maximum values of $\dot{M}$ and $\dot{a}$ are in mass transfer state in binary star system , in other words the maximum values of $\dot{a}$ depend on the mass transfer between the two component stars of the binary star system.

Key words

Binary stars, Astrophysics, Roche lobe, Mass transfer.

Article info

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تغير البعد نتيجة انتقال وفقدان الكتلة في النظامين النجميين الثنائيين M(13.6+8) وM(13+10)

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الخلاصة

في هذا البحث تم دراسة التغير في البعد لنجمين في نظامين ثنائيين وهما M(13.6+8) وM(13+10) ومن خلال الحسابات تم استخراج قيمة $\dot{M}$(معدل انتقال الكتلة) لمرحلتين من المراحل الديناميكية لحالة الكتلة وهما مرحلة فقدان الكتلة ومرحلة انتقال الكتلة كل حسب طريقته ومن خلال استخراج قيمة $\dot{M}$ تم استخراج قيمة $\dot{a}$ (التغير في البعد بين النجمين) فقط في مرحلة انتقال الكتلة باستخدام نموذج رياضي اما في مرحلة فقدان الكتلة فقد تم حساب $\dot{M}$ و $\dot{a}$ من خلال التغير والفرق بين قيم كل منهما في اوقات مختلفة من اوقات تطور النظام النجمي الثنائي وقد وجد ان قيم $\dot{M}$ و $\dot{a}$ العظمى تكون في حالة مرحلة انتقال الكتلة في النظام النجمي الثنائي اي ان قيم $\dot{a}$ العظمى يعتمد على انتقال الكتلة بين النجمين المكونين لنظام النجوم الثنائية.

Introduction

Most of the stars in our universe are born in binary systems. The binary star system can be classified into two categories:- Close binary stars and wide binary stars. In close binaries the initial orbital period is less than few years while in wide binaries the inverse is true. The course of evolution of the binary can be affected with the tidal force between the stars of the binary system [1].

The known four types of binary star systems are visual binaries which its image can be distinguished, Spectroscopic binaries which also can be distinguished by the displacement of the wavelength of their spectral lines, and Eclipsing binaries which can be recognized by the periodic drops in brightness as the couple stars periodically eclipse each other. The two assumed binary system under studying will be visual binary star systems. Nearly 85% of all stars in the universe are binaries. The physical parameters of binary star systems are about mass, distance between each other, luminosity, orbital period, mass transfer and etc.[2].

The orbital period and the separation of the binary stars

The binary star system is about couple stars orbit each other under their mutual gravitational attraction. The distance between the two stars is called the separation (a) and when the star completes one cycle period, it is called the orbital period (P).

The total mass of the binary star can be calculated as the following equation:-

$$M_1 + M_2 = \frac{a^3}{P^2} \qquad (1)[2]$$

Where M_1 is mass of the primary star, M_2 is mass of the secondary star.[1].

The importance of the binary star system appeared clearly because the mass of the binary star can be calculated if the calculation of their orbit is done. And also indirectly the mass-luminosity relation could be extracted. [3]

There is another classification of the binary star depending on the distance between the binary star as follow:-

1-Detached binaries

They are binary stars where each component is within its Roche lobe. The stars have no maximum influence on each other .Most binaries fall in this category

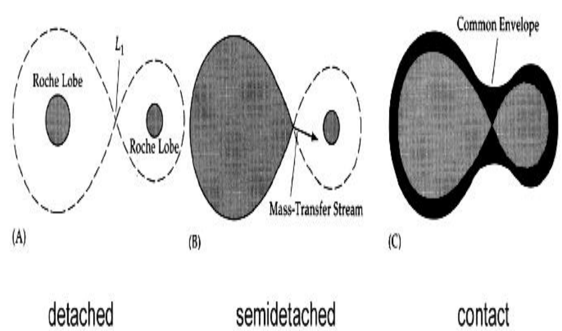
2-Semidetached binary stars

They are binary stars which one of the components fills its Roche lobe but the other doesn't. The mass transfer in this case will commence and dominate the evolution stage. The matter will be transferred from the donor star to the other.

3-Contact binary stars

They are binary stars in which both components of the double stars will fill their Roche lobe. The common envelope will be formed in the upper atmosphere of the binary system. The two stars will probably merge[3].The above three types of binary stars have been shown as in Fig.1[4].

Fig.1: The three types of the binary star systems depending on their Roche lobe [4].



The orbital period of the binary stars differs from system to system depending on the separation between them, e.g. it could be few days or also hundreds of thousands of years.[3]

The binary star interactions play an important role to determine the state of its compact component. The component object may be White dwarf (WD), Neutron star (NS) or Black hole (BH) depending on the evolutionary stage and mass of the star. For example, star with mass less than $2.3M_\odot$ can evolve to White dwarfs.

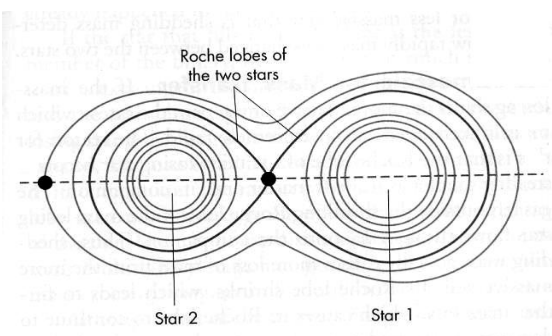
A star in binary star system with mass

larger than $12M_\odot$ can form a Neutron star in evolutionary stage.A Black holes compact can be existed when the Neutron star core collapses inwardly with mass between $(25\text{-}40)M_\odot$.[5]

Both the rotational and gravitational energy per unit mass near the surface of stars generate the surface called equipotential surface .Near the stellar centers these surfaces are usually spherical.These surfaces of the binary stars denoted as Roche surfaces after the French mathematician E.Roche who described them in 1873.[6]

The surface will form a common envelope in the binary star.The Roche lobe is the region around star in a binary system in which the gravity of that star dominates as in Fig.2.[1]

Fig.2: The Roche lobe and quipotential



surface of the binary star system [2].

Usually the size of the Roche lobe in one component of the binary stars can be calculated by using Eggleton formula[1]

$$R_L = \frac{0.49q^{2/3}}{0.69q^{2/3}+\ln(1+q^{1/3})}a \qquad (2)[7].$$

Where R_L is the radius of Roche lobe, q is the mass ratio=M_2/M_1[7].

Sometimes the R_L is called effective radius[6]

Paczynski also calculated the effective Roche lobe radius R_L of the donor star in binary system as follow:-

$$R_{L_2} = 0.462\left(\frac{M_2}{M}\right)^{1/3} a \qquad (3)[8].$$

Where M_2 is the mass of the donor star, M is the total mass, and a is the separation of the binary star[8].

The mass transfer phenomenon

In evolution course of the binary star system, if one of the stars expands and fills its Roche lobe then matter will flow from it to the companion star. The orbital parameters of the binary star would be changed clearly due to the mass transfer process.

The total orbital angular momentum of the binary star J can be stated as:-

$$J = M_1 M_2\sqrt{\frac{Ga}{M}} \qquad (4)[1]$$

Where M is the total mass of the binary system. Then

$$\frac{\dot a}{a} = \frac{2\dot J}{J} - \frac{2\dot M_1}{M_1} - \frac{2\dot M_2}{M} + \frac{\dot M}{M} \qquad (5)[1]$$

in the present work the conservative case has been adopted i.e. no matter or angular momentum leaves the binary star system, then both $\dot M$ and $\dot J$ will be zeroed. This leads to

$$\frac{\dot a}{a} = -\frac{2\dot M_1}{M_1}\left(1-\frac{M_1}{M_2}\right) \qquad (6)[1]$$

notice that $\dot M_2 = -\dot M_1$ because of the mass conservation[1]

It is important to say that at the early case of binary evolution, the mass transfer between the components and the orbital momentum loss play a great dynamical role [9].

Finally the most general form of the Eeq. (5) has been given by:-

$$\frac{\dot a}{a} = -2\left(1+(\beta-1)\frac{M_2}{M_1}-\frac{\beta}{2}\frac{M_2}{M}\right)\frac{\dot M_2}{M_2}+\frac{2\dot J_{orb}}{J_{orb}} \qquad (7)[9]$$

where β is the fraction of the ejected matter which leaves the system $(0 \le \beta \le 1)$ [9].

Calculations and discussion

1- (13.6+8) M⊙ Binary star system

First the mass of the primary star has been taken into account in the calculations.
The reduction in mass of the primary is due to two main processes: the mass loss and the mass transfer.

Initially the data of the binary system parameters have been gathering from Table1. Then according to the mass dynamics, the life of the binary star under studying can be divided into two stages: Mass loss and Mass transfer. Table1 explains the various phases of binary star system initially and finally .

Table 1: The evolutionary stage of binary star system(13.6+8)$M_\odot$,including Mass transfer phase.[10]

Time (Myr)	**M_1 ($M_\odot$)**	**M_2 ($M_\odot$)**	**Separation a ($R_\odot$)**	**What's Happening**
0.0000	13.600	8.000	100.168	[1]ZAMS
14.7175	13.341	8.004	101.277	Stellar evolution
14.7418	13.338	8.004	101.329	M_1 fills RL1
14.7497	13.330	8.010	101.279	Mass transfer
14.7841	3.284	18.051	298.168	End of Mass Transfer
14.8029	3.262	18.067	297.662	Stellar evolution
16.8681	2.978	17.997	302.713	Supernova
17.0546	1.346	17.993	326.675	Stellar evolution
22.9777	1.346	17.533	334.431	Stellar evolution
22.9963	1.346	17.521	334.674	Stellar evolution
23.0150	1.346	17.491	335.343	M_2 fills Roche lobe
23.0150	1.346	4.711	1.697	End common envelope spiral in
23.5695	1.353	4.470	1.296	M_2 fills Roche lobe again
24.3720	1.383	3.927	0.932	Supernova
24.3720	1.383	1.371	2.125	Stellar evolution
653.4350	1.383	1.371	0.000	M_1,M_2 fill RL1,RL2
653.4350	2.754	0.000	0.000	Coalescence of [2]NS+NS

[1]Zero-age main sequence star,[2] Neutron Star

In Table(2),the calculation of $\dot{M}$ and $\dot{a}$ have been evaluated. $\dot{M}$ and $\dot{a}$ have been computed according to the mass status ,if the mass phase is mass loss then $\dot{M}$ can be computed by simple formula $\dot{M} = \frac{\Delta M_1}{\Delta Time}$ and $\dot{a}$ also can be computed by:-

$\dot{a} = \frac{\Delta Separation}{\Delta Time}$,if the mass phase is mass transfer then $\dot{M}$ and $\dot{a}$ can be computed by $\dot{M} = \frac{\Delta M_1}{\Delta Time}$ and Eq.(6) respectively.

Table 2: The results of the mass transfer process and the distance vartiation in the binary star system (13.6+8)$M_\odot$

Time (Myr)	ΔTime (yr)	ΔM_1 ($M_\odot$)	($M_\odot$/yr)$\dot{M}$	($R_\odot$/yr)$\dot{a}$	Mass status
14.7175	14.7175×10^{6}	-0.259	-1.7598×10^{-8}	7.5352×10^{-8}	[3]ML
14.7418	24300	-0.003	-1.2346×10^{-7}	6.2551×10^{-6}	[4]MT
14.7497	7900	-0.008	-1.0127×10^{-6}	6.55×10^{-4}	MT
14.7841	34400	-10.046	-2.9203×10^{-4}	14.1354	MT
14.8029	18800	-0.022	-1.1702×10^{-6}	0.0053	ML
16.8681	2065200	-0.2840	-1.3752×10^{-7}	2.4458×10^{-6}	ML
17.0546	186500	-1.6320	-8.7507×10^{-6}	1.2848×10^{-4}	ML
22.9777	5923100	0	0	1.3094^{-6}	ML
22.9963	18600	0	0	1.3065×10^{-5}	ML
23.0150	18700	0	0	3.5775×10^{-5}	MT
23.5695	554500	0.0070	1.2624×10^{-8}	3.37×10^{-7}	MT
24.3720	802500	0.0300	3.7383×10^{-8}	5.03×10^{-7}	ML
653.4350	629063000	0	0	3.3780×10^{-9}	ML

[3]Mass loss,[4]Mass transfer

The sign(-) of $\dot{M}$ means that the primary star loses the mass to the secondary star. The primary star would shed matter into secondary until the secondary star would fill its Roche lobe and reversely it would shed matter into the primary star that means $\dot{M}$ will be positive after 23.015×10^{6}yr. Of course the separation of the two stars will be affected due to these dynamics changes. First $\dot{a}$ will increase due to mass loss of the primary star of the binary system, then it will increase more and more. $\dot{a}$ reaches its maximum value at 14.7841×10^{6}yr in mass transfer phase. As $\dot{M}$ increases $\dot{a}$ will increases and vice versa. At 14.7841Myr (1Myr=10^{6}yr), the configuration of the binary star system has critical case leading to Supernova. This is clear that in Fig.4 as $\dot{M}$ increases, $\dot{a}$ will increase.

In Fig.5, the peak of $\dot{a}$ clearly has been seen in 14.1354Myr (Critical case), Sharp drops. And after 14.1354Myr the $\dot{a}$ nearly will be steady and constant with proceeding time.

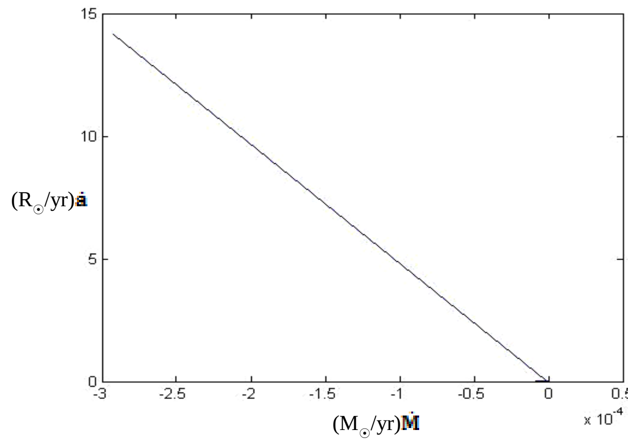


Fig.4: The relation between $\dot{a}$ and $\dot{M}$ in binary star system(13.6+8)$M_\odot$

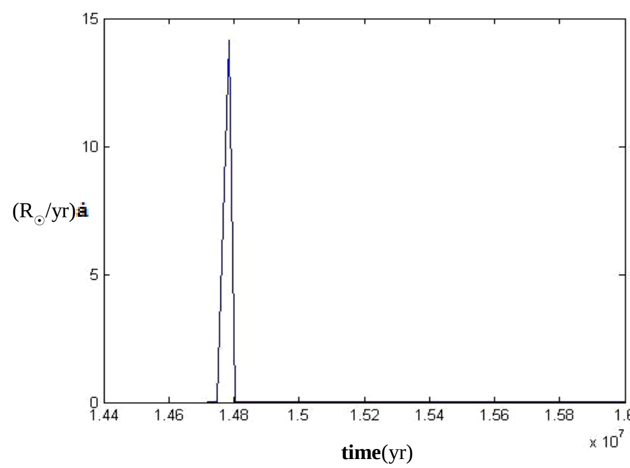


Fig.5: The relation between $\dot{a}$ and time in binary star system (13.6+8) $M_\odot$

Fig.6 shows initially at early time, $\dot{M}$ suffers from dramatic changes, $\dot{M}$ starts with minmum value and increased with time until

the mass transfer stage which affects on the $\dot{M}$, $\dot{M}$ in mass transfer stage
will increase with time.After finishing of mass transfer $\dot{M}$ will decrease sufficiently. $\dot{M}$ as in Fig.6 would be nearly study and constant after 22.9777Myr.

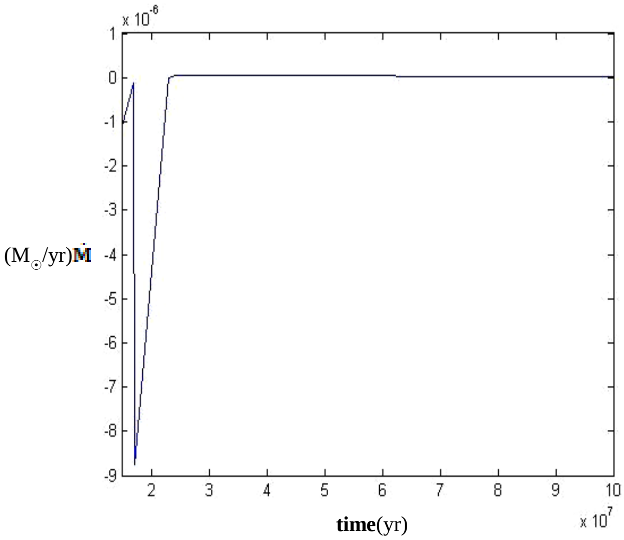


***Fig.6:** The relation between $\dot{M}$ and time in binary star system (13.6+8) $M_{\odot}$*

Similar to the previous mentioned binary star system ,the data of the (13+10)$M_{\odot}$ binary star system has been gathered from Table3.There are also two stage of mass process:-mass loss and mass transfer. The results in Table4 shows that $\dot{M}$ and $\dot{a}$ in system (13+10)$M_{\odot}$ have been calculated as the same method in Table2 in system(13.6+8)$M_{\odot}$.
First the $\dot{M}$ in MT phase increases with time progression. In 16.1359Myr it will decrease and sequentially $\dot{M}$ will increase again until its value vanished in 23.8042Myr and 23.8204Myr where the system will be converted to Neutron star. $\dot{a}$ also will increase with time specially in mass transfer period. Then it will decrease, and in 18.3771Myr will increase. When the secondary star sheds the matter into primary star, the $\dot{a}$ values will increase.

2- (13+10)$M_{\odot}$ Binary star system

***Table 3:** The evolutionary stage of binary star system(13+10)$M_{\odot}$,including Mass transfer phase.[10]*

Time (Myr)	M_1 ($M_{\odot}$)	M_2 ($M_{\odot}$)	Separation ($R_{\odot}$)	What's Happening?
0.0000	13.000	10.000	102.287	[1]ZAMS
15.7681	12.773	9.960	103.370	Stellar evolution
15.7821	12.772	9.960	103.398	M_1 fills RL1
15.8036	3.040	12.741	73.167	End of Mass Transfer
16.1359	3.016	12.738	73.167	Stellar evolution
18.1694	2.796	12.713	74.434	Supernova
18.3771	1.333	12.722	82.218	Stellar evolution
23.8042	1.333	12.596	82.910	Stellar evolution
23.8204	1.333	12.595	83.009	M_2 fills RL2
23.8204	[2]NS spirals into core of giant			

[1]Zero-age main sequence star,[2]Neutron Star

***Table 4:** The results of the mass transfer process and the distance vartiation in the binary star system (13+10)$M_{\odot}$.*

Time (Myr)	ΔTime (yr)	ΔM_1 ($M_\odot$)	($M_\odot$/yr)$\dot{M}$	($R_\odot$/yr)$\dot{a}$	Mass status
15.7681	15768100	-0.227	-1.4396×10^{-8}	6.8683×10^{-8}	[3]ML
15.7821	14000	-0.001	-7.1429×10^{-8}	2.0000×10^{-6}	[4]MT
15.8036	21500	-9.732	-4.5265×10^{-4}	2.6931	MT
16.1359	332300	-0.0240	-7.2224×10^{-8}	0	ML
18.1694	2033500	-0.2200	-1.0819×10^{-7}	6.2306×10^{-7}	ML
18.3771	207700	-1.4630	-7.0438×10^{-6}	3.7477×10^{-5}	ML
23.8042	5427100	0	0	1.2751×10^{-7}	ML
23.8204	16200	0	0	6.1111×10^{-6}	ML

[3]Mass loss,[4]Mass transfer

In Fig.7 the relation between $\dot{a}$ and $\dot{M}$ nearly study proportionally especially in mass transfer phase.

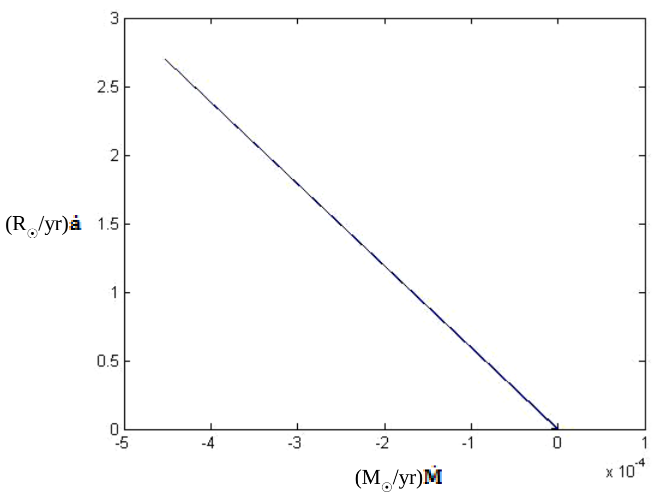


Fig.7: The relation between $\dot{a}$ and $\dot{M}$ in binary star system(13+10)$M_\odot$

In Fig.8 the maximum value of $\dot{a}$ versus time is in 15.8036Myr and has value 2.6931 $R_\odot$/yr and then it will be inear proportion.

In Fig.9, $\dot{M}$ has maximum value at early evolution of the binary star when the primary star fills its Roche lobe and shedding materials into the secondary star at 15.7821Myr which is represented by peak hump as shown in Fig.9. Then it will be semilinear with time after 16.1359Myr.

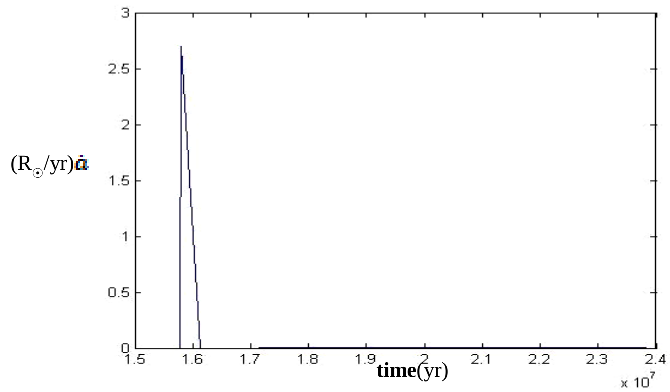


Fig.8: The relation between $\dot{a}$ and time in binary star system (13+10) $M_\odot$

In Fig.9, $\dot{M}$ has maximum value at early evolution of the binary star when the primary star fills its Roche lobe and shedding materials into the secondary star at 15.7821Myr which is represented by peak hump as shown in Fig.9 then it will be semilinear with time after 16.1359Myr.

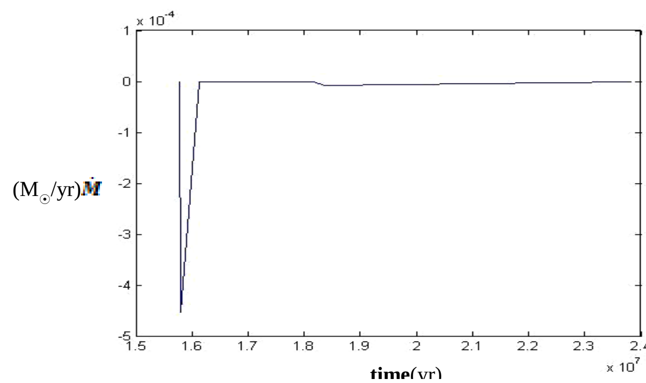


Fig.9: The relation between $\dot{M}$ and time in binary star system (13.6+8) $M_\odot$

Conclusions

1. There is a linear relationship between $\dot{a}$ and $\dot{M}$.

2. M_1 and M_2 will be affected due to mass transfer process either increment or decrement.
3. $\dot{a}$ and $\dot{M}$ have maximum values at mass transfer process.
4. There are two mass dynamic process of the binary star system:-Mass transfer and Mass loss.
5. $\dot{a}$ and $\dot{M}$ can be different from one binary star system to another due to their masses and separations.

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