MASS LOSS FROM CONTACT BINARY SYSTEMS AND THEIR DYNAMICAL EVOLUTION

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1. INTRODUCTION

When there is mass loss from a binary system, the lost mass carries energy and angular momentum out of the system. Therefore, the remaining system must adjust its orbital parameters to the changing values of the total kinematic energy E and the total angular momentum N as the total mass M decreases. The parameters concerned here are : the fractional mass μ , the semi-major axis a , and the eccentricity e .

Mass loss from binaries takes place preferentially through the second Lagrangian point which we will denote by L . Kuiper (1941) has shown that two asymptotic orbits exist for particles leaving L with zero relative velocity. Most particles that pass L outward converge to one of the asymptotic orbit that leads a particle far from the system. Therefore, the specific energy f (in units of GM/a) and the specific angular momentum K (in units of $(GMa)^{1/2}$) of escaping particles are almost the same as those of a particle leaving L in the direction of the line connecting two centers of mass ; $f=0$ and $K=1.7$. These values should be compared to the mean values of the system and to the values at L . For the case of two point masses of equal weight moving in circular orbits, the mean values are : $f=-\infty$, $K=0.25$ and at L : $f=-0.29$, $K=1.44$. The infinity of the mean energy is caused by the point structure of the components and will be removed if realistic models are introduced.

Some of the particles leaving L in the direction opposite to the motion of rotation converge to another asymptotic orbit that hits the Lagrangian lobe immediately after the departure from L . These particles have smaller azimuthal velocity than those converging to the orbit that permits escape from the system. Therefore, the centrifugal force cannot balance the gravity. In the case of mass loss from a contact binary, we have to think only of the former particles as far as the losses of energy and angular momentum from the system are concerned. This situation is not altered for non-zero initial relative velocity at L (Nariai 1975, 1977).

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We may call the mechanism of acceleration of particles by two rotating bodies as "the gravitational stellar accelerator". The rotating non-axisymmetric gravitational field works as a sling. If we increase the initial relative velocity at L , the escaping particle spend less time in the region where the stellar accelerator functions effectively. However, it should be noted that the ratio of the specific angular momentum and the mean specific angular momentum is about 6 at L and this ratio becomes 7 at infinity. Therefore, as far as the transport of angular momentum is concerned, we may say that the most important part lies within the Lagrangian lobe. The behavior of the remaining system caused by the loss of angular momentum is not affected very much by the efficiency of the "stellar accelerator" outside the Lagrangian lobe as long as mass loss takes place through L . When mass loss is caused by stellar wind originating from corona surrounding the binary, it is supposed that the velocity of the wind at L , is larger than the velocity of the orbital motion. In such a case, a particle will escape from the system before the stellar accelerator works effectively, and K will remain near its initial value.

Nariai and Sugimoto (1976) have studied the effects of mass loss on the remaining system with some assumption on the fractional mass and without taking account of the angular moment of rotation. They have found that the eccentricity increases and the semi-major axis decreases very rapidly if there is mass loss from L . According to Zahn (1976), the characteristic times for circularization and synchronization caused by the tidal effects are quite small if the component stars have convective envelopes. They are 2×10^4 years and 10^6 years, respectively, for a system of $\mu=0.5$ and the orbital period of 1 day. Assuming that the characteristic time of mass loss through the stellar wind is smaller than the life of main sequence stars but larger than the tidal characteristic times, we will study the dynamical evolution of a contact binary in the following section.

2. DYNAMICAL EVOLUTION

We assume that the orbit of the binary is circular and the both components rotate at the synchronous rate. Then the total angular momentum N is written as

$$N = M(GMa)^{1/2} \left(m_1 m_2 + \sum m_i s_i^{\,2} \right) , \qquad (1)$$

where m_i is the fractional mass of the i-th component and s_i is the ratio of the gyration radius d_i to the semi-major axis a . $\sum$ represents the sum $\sum_{i=1}^{2}$. The total kinematic energy E is the sum of the potential and kinetic energies of the orbital motion and the rotational energy of the component stars. It is written as

$$E = N(GM/2a) \left(-m_1 m_2 + \sum m_i s_i^{\,2}\right) . \qquad (2)$$

The gravitational energy and the internal energy of the component stars, the production of energy by nuclear reactions and the loss of energy from the photosphere do not appear in equation (2). The variations δN and δE are written with the orbital parameters and with the total mass as

$$\delta N = M(GMa)^{1/2}\{ P\delta \ln M + Q\delta \ln a + (R-S)\delta\mu \} , \tag{3}$$

$$\delta E = -M(GM/2a)\{ T\delta \ln M + Q\delta \ln a + (R+S)\delta\mu \} , \tag{4}$$

where

$$P = 1.5m_1m_2 + \sum (1.5+2\alpha_i)m_is_i^2) , \tag{5}$$

$$Q = 0.5(m_im_2 - 3 \sum m_is_i^2) , \tag{6}$$

$$R = m_1 - m_2 , \tag{7}$$

$$S = (1+2\alpha_1)s_1^2 - (1+2\alpha_2)s_2^2 , \tag{8}$$

$$T = 2m_1m_2 - \sum 2(1+\alpha_i)m_is_i^2 , \tag{9}$$

and

$$\alpha_i = d \ln d_i / d \ln M . \tag{10}$$

When the process of mass loss is very slow and the structure of the components do not change, we have $r \propto M$, therefore $\alpha_i=1$. α_i is a quantity of the order of 1, and it appears always as a factor of s_i^2. The ratio of the gyration radius to the radius of the star is 0.27 for a polytrope of index 3. For a star with the polytropic index of approximately three, s_i^2 is given by $0.1(r_i/a)^2$.

We can write δN and δE as functions of the lost mass δM using two parameters K and F as

$$\delta N = K(GMa)^{1/2}\delta M , \tag{11}$$

$$\delta E = F(GM/2a)\ \delta M . \tag{12}$$

We will take $K=1.4$ as we are thinking of mass loss by stellar wind through L . If we are concerned with the quiet ejection, we have to take $K=1.7$. If we include the effect of magnetic field, more angular momentum can be carried away by the escaping mass and K will be larger than the corresponding values without magnetic field.

Three mechanisms contribute to F . The first contribution is given by the stellar accelerator and will be written as $v^2(a/GM)$ for ejection with zero initial relative velocity. v denotes the velocity at infinity. For ejection from the corona, it is written as $(v^2-2U_c)(a/GM)$ where U_c represents the specific internal energy of coronal gas. In both cases, this quantity is almost zero. The second contribution comes from dissipation through the tidal effects. This quantity is always positive. The third contribution comes from the structural change of the component stars. Let us think of what happens in one of the components which is compressed by accreting mass. As mass is accreted on it, the star is compressed and rotates more rapidly than before violating the synchronism. A part of the excess rotational energy is transferred to the orbital motion by the tidal coupling. Thus, a binary can convert a part of the difference in the potential energy into the kinematic energy when there is mass transfer between the components. F can be either positive or negative.

From equations (3), (4), (11), and (12), we can derive the derivatives of $\ln a$ and μ as functions of $\ln M$;

$$\frac{d \ln a}{d \ln M} = \frac{R(K+F-P+T)+S(K-F-P-T)}{Q(3R-S)} \tag{13}$$

$$\frac{d \mu}{d \ln M} = \frac{2K-F-2P-T}{3R-S} \tag{14}$$

3. DEGREE OF CONTACT

It is interesting to know how the degree of contact changes with mass loss. The degree of contact c is given by

$$c=(\phi-\phi_2)(\phi_1-\phi_2) \tag{15}$$

where ϕ represents the potential at the surface of the common envelope and ϕ_1 and ϕ_2 are the potentials at the inner and the second Lagrangian points, respectively. It should be noted that $(da/d\mu)_c$ is positive for the region of μ [0, 0.5]. If F is very large, we have negative gradient

$$d \ln a/d\mu=-(R-S)/ \quad Q \tag{16}$$

and the binary will evolve from the stage of thin contact (c=1) to the stage of contact at L(c=0) rapidly. If F is close to zero, $(da/d\mu)$ is positive. Therefore, we can expect that the degree of contact of a contact binary remain unchanged for a long time. Detailed calculations show that the degree of contact of contact binaries should be close to 1(thin contact). For details, see Nariai (1979).

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DISCUSSION FOLLOWING NARIAI

Vanbeveren: In the calculations of particle motions in binary systems one usually uses a Roche geometry. It may be that radiation forces and shadow effects change the Roche geometry (see e.g. two papers published in A & A, 54, 877 and Astrophys. and Space Sci. 57, 41). Could you comment on that in connection with your calculations?

Nariai: I do not think that radiation changes the situation for systems with low luminosity such as W UMa-type binaries.

Eaton (in reply to Vanbeveren's comment): Comment on modification of Roche lobes by radiation pressure: This will be important only for the hottest stars which should be gravity-darkened. With von Zeipel gravity darkening, the shape and size of the gravitational equipotentials will not be changed. Hence, radiation pressure should not affect the shape of the Roche lobe which determines the limiting size of a binary component. I made this comment in an article appearing in Acta Astronomica, 28.

Wilson: I'd like to point out that I also made this same comment at last year's eclipsing binary symposium in Victoria.

Zuiderwijk (comment on a remark by Vanbeveren): Apart from the fact that the concept of separating radiation pressure from the total pressure in the stellar interior and atmosphere is basically wrong, I would like to make another comment on Schuerman's (1972) model. The major result from his computations, concerning the "opening of the critical surface" near L_1, is only an artifact of his assumption of a spherically symmetric radiation field. This assumption also means that gravity darkening is neglected in the model. As gravity darkening is directly related to hydrostatic equilibrium, we can conclude that Schuerman's model is also not in hydrostatic equilibrium.

Re: Schuerman, D.W., Astrophys. Space Sci. 19, 351, 1972.

Kondo: There is no time now for me to discuss whose radiation pressure model is appropriate. It is a complex problem. For instance, the shadow effects as discussed by Vanbeveren must be taken into account. I simply wish to point out that radiation pressure and other effects must be properly treated for discussions of the critical equipotential surfaces.