STELLAR EVOLUTION AND CLOSE BINARIES

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A general scheme of evolution of close binaries is outlined. Many types of observed systems are classified according to their evolutionary status. Present theory can account reasonably well for the mass transfer between the two components. There is no satisfactory theory of mass and angular momentum loss from binary (as well as single) stars. Most close binaries sooner or later should develop extended common envelopes. A loss of a common envelope may remove a large fraction of mass and most of angular momentum from a binary, and leave as a remnant a very short period and highly evolved system. Binary nuclei of planetary nebulae, cataclysmic variables and some X-ray binaries are produced this way.

I shall present here a picture of the evolution of close binary systems (CBS) as it is understood now. This is not intended to be a review, and no attempt has been made to make the list of references complete. Usually I shall refer the first paper on a given subject and/or one of the recent ones, where a large number of other references can be found. There are many reviews and proceedings of various symposia that deal with close binaries. Here are some: Annual Review of Astronomy and Astrophysics (9, 183, 14, 119, 15, 127, 16, 171, 241), IAU Symposia No. 73, 83, 88, IAU Colloquia No. 42, 46, 53. I shall try to emphasize what is known and what is not known, and how various observed systems fit into the theoretical evolutionary scheme. Because of my background I shall give more references to theoretical papers. Nevertheless, I am convinced that it was the theory of close binaries that was guided in its development by the observations, not other way around. In fact the theory predicted very few new phenomena and very few new types of binaries. But it managed to account, at least qualitatively, for the major evolutionary processes, and made it possible to arrange the observed systems into the evolutionary sequences.

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A majority of known stars are not single. According to the recent surveys made by Abt and Levy (1976, 1978), more than 50 percent of B-type stars are either binary or multiple systems. Among the F and G type stars this fraction reaches 90 percent. For a binary composed of unevolved components the mass ratio is usually very close to unity, though large mass ratios are also found. There is no well developed theory of origin of binaries. It is frequently suggested that binaries form either through a fission of rapidly rotating protostars, or through a capture of one star by another. Presumably fission produces mass ratios close to unity, while capture can lead to any mass ratio. Unfortunately, very few, or no binaries with pre main sequence components are well known.

A pair of stars is called a close binary system if the two components can interact. The interaction may be due to a number of reasons. Here are some:

1. tides,
2. radiation,
3. magnetic fields,
4. accretion from a stellar wind,
5. mass transfer through the Roche lobe overflow,
6. common envelope.

The consequences of mass transfer between the components are well studied theoretically. Perhaps this is the reason for belief that this type of interaction is the most important for the evolution of close binaries. Accordingly, the following classification is used for close binaries:

a/ detached,
b/ semidetached,
c/ contact,
d/ common envelope.

Detached binaries have both components smaller than their Roche (or tidal) lobes. That means that tidal forces cannot drive direct mass transfer from one component to another. Only weak interaction (points 1-4 on the list above) between the two stars is possible. If one of the components expands so much that it fills up its Roche (or tidal) lobe, the gravitational pull from the companion drives mass transfer through the vicinity of the inner Lagrangian point (the L1 point). It is known from model computations that as much as 80 percent of mass of the star filling its Roche lobe may be transferred in this manner on a Kelvin-Helmholtz (i.e. thermal) time scale. Such binary is called semide-

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tached. It may happen that while one star fills its Roche lobe the companion expands so that it also fills its Roche lobe. The two stars come into direct contact, and a contact binary is formed. The two stars may expand together beyond their Roche lobes, and up to a certain point and a solid body rotation of the whole system may be maintained, at least in principle. Eventually, the common surface may reach the outer Lagrangian point (the L2 point), and an attempt to expand beyond, while maintaining a solid body rotation must lead to mass loss from the binary through the vicinity of the L2 point. The common envelope may extend beyond the L2 point and not be lost from the binary provided it does not rotate synchronously with the orbital motion of the two stellar cores. In the absence of a solid body rotation the L2 point has no dynamical significance. A system with a surface beyond the outer Lagrangian point is called a common envelope binary.

Orbital period of a binary cannot be too long if a semidetached, contact, or common envelope phase is to be encountered during the evolution. Let us consider as an example a binary with the initial masses of the primary and secondary components of 5 and 2.5 solar masses, respectively. With the two stars on the zero age main sequence a semidetached binary would have an orbital period of 0.65 days. If the primary is to fill its Roche lobe before exhausting hydrogen fuel in its core, the orbital period must be less than 1.5 days. In this case the binary is said to undergo case A of mass transfer during the semidetached phase of evolution. If the orbital period is longer than 1.5 days but shorter than 3 months, the primary will fill its Roche lobe after exhausting hydrogen in the center, but before helium will have been ignited. Case B of mass transfer follows. If the orbital period is above 3 months but below 12 years the primary will fill its Roche lobe after helium ignition but before carbon ignition. Case C of mass transfer follows. Finally, if the orbital period is longer than 12 years a semidetached system cannot be formed. The specific limits for the orbital period given above would be different if different masses were chosen for the two components of a binary. However, the difference of periods would not be larger than a factor 2 or 3.

Most model computations for the evolution of close binaries were made under the so called "conservative" assumptions:

$$M = M_1 + M_2 = \text{const.}$$

$$J = \left(\frac{G A}{M_1 + M_2} \right)^{\frac{1}{2}} M_1 M_2 = \text{const.},$$

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i.e. the total mass of the binary, M, and the orbital angular momentum, J, are conserved during the process of mass transfer. The binary orbit was assumed to be circular, with A being the separation between centers of the two components. Evolution of real binaries is certainly nonconservative, i.e. they lose mass and angular momentum. A nice example is provided by an eclipsing binary AS Eri, for which very good observational elements (Popper 1973) and a very good theoretical model (Refsdal, Roth and Weigert 1974) are available. The most recent summary of the subject is provided by Ziolkowski (1979) and by Hall (1979). Nevertheless, it seems that in most cases the "nonconservative" evolution does not change the qualitative picture achieved with "conservative" model computations.

As practically nothing is known about the pre main sequence binaries, I shall begin my description of the evolution with the two components on the zero age main sequence, the binary being detached at this time. As a result of nuclear evolution the two stars will gradually expand, the more massive expanding faster. I shall always refer to it as a primary, even if it becomes the less massive of the two components as a result of the subsequent evolution. Many examples are known of the detached but somewhat evolved binaries, with the still more massive primary being more expanded than the secondary. The best known class of this type are RS CVn binaries, with each star somewhat more massive than the Sun. They received a lot of attention recently because of their activity leading to fairly strong radio and X-ray emission. Many references can be found in a recent paper by Guy Morgan and Eggleton (1979), De Campli and Baliunas (1979), and in the Proceedings of the IAU Symposium No. 88 held in Toronto August 1979. There are also more massive detached and evolved binaries, like V380 Cyg (Semeniuk and Paczynski 1968).

As soon as the Roche lobe is filled by the primary a semidetached binary is formed, and a rapid mass transfer from the primary to the secondary begins for the first time. On a Kelvin-Helmholtz time scale the mass ratio of the binary is reversed. This time scale is given as

$$\tau_{K-H} = 3 \times 10^{7} \text{ years} \left(\frac{M}{M_{\odot}}\right)^{2} \frac{R_{\odot}}{R} \frac{L_{\odot}}{L} ,$$

where M, R, and L are the mass, radius and luminosity of the primary when it filled its Roche lobe. The maximum rate of mass transfer may be estimated as

$$M_{max} \approx M / \tau_{K-H} .$$

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Initially, while the mass losing primary is the more massive of the two components the orbital period decreases. The best example is provided by SV Cen (Nakamura, Saio and Sugimoto 1978), with the orbital period of 1.66 days, and the primary and secondary masses of 11.1 and 9.3 solar masses, respectively. The observed time scale for the decrease of period is 50 000 years. When the mass ratio is reversed and the mass transfer continues, then the orbital period increases. One of the good examples is provided by U Cep, which has the orbital period of 2.49 days, and the primary and secondary masses of 2.8 and 4.2 solar masses, respectively. The observed time scale for the increase of orbital period is 1.4 milion years. Many references to the observed period changes are given by Kreiner and Ziolkowski (1978) and Hall (1979).

The rapid phase of mass transfer may destroy the binary nature of some systems. As a result of rapid mass accretion the secondary component expands and may fill its own Roche lobe. A contact system is produced, and the evolution proceeds through a common envelope phase. The first study of this problem was never published (Benson 1970). The more recent publications are those of Flannery and Ulrich (1977), Kippenhahn and Meyer-Hofmeister (1977), Neo, Miyaji, Nomoto and Sugimoto (1977). It is possible that the observed deficiency of semidetached binaries in case A of mass transfer may be due to the formation of contact and common envelope systems during the first phase of rapid mass transfer.

Most binaries undergoing case B of evolution should survive the first phase of rapid mass transfer because the separation of their components is much larger. The evolution subsequent to the rapid phase depends on the initial mass of the primary. I shall consider massive systems first. Many of those are observed during the rapid mass transfer. Beta Lyrae is the classic example (Ziolkowski 1976). The rapid mass transfer is terminated with the core helium ignition in the primary, which is accompanied with a decrease of the primary's radius. An evolved, post mass transfer binary is formed. The primary is now a helium star while the secondary may be somewhat above the main sequence. The best known systems of this type are Wolf-Rayet binaries (Paczynski 1966, 1967b). The primary is likely to exhaust its nuclear fuel first and to explode as a supernova, leaving a neutron star or a black hole as a remnant. Evolving massive secondary will be losing some matter in a wind. As the secondary approaches its Roche lobe, the increasingly large fraction of its wind is accreted by the compact primary giving rise to a strong X-ray emission. The system is now a massive X-ray binary (van den Heuvel and Heise 1972, Massevitch, Tutukov and Yungelson 1976, Ziolkowski 1977). After some time the secondary will overflow its Roche lobe and a phase of rapid mass transfer will begin for the second time, this time in a reversed direction. Because of the extreme mass ratio a common envelope binary is formed (Taam, Bodenheimer and Ostriker 1978). I shall discuss this phase later.

Case B evolution in a low mass binary proceeds differently. The first phase of rapid mass transfer is terminated with an onset of electron degeneracy in the helium core of the primary component (Paczynski 1966). After that the system remains semidetached but the mass transfer proceeds slowly on a nuclear time scale of hydrogen burning shell (Kippenhahn, Thomas and Weigert 1968). The binary is a typical Algol type system, with a main sequence more massive secondary, and a subgiant undermassive primary. This phase of evolution terminates either with a helium flash in the degenerate care of the primary component, or more likely by the near exhaustion of the primary's hydrogen envelope. In either case the binary becomes detached again. After some time the primary evolves to become a degenerate dwarf, while the secondary is a much more massive main sequence star. The binary nature of the system may be difficult to discover observationally. BD + 3° 5357 (Dworetsky, Lanning, Etzel and Patenaude 1977) is a possible example. Finally, the secondary evolves away from the main sequence and expands too. As soon as the Roche lobe is overflown a second phase of rapid mass transfer takes place, now in the reversed direction. Because of the extreme mass ratio a common envelope binary is formed soon. This phase will be discussed later.

It is not possible to say precisely at which mass of the primary component there is a transition from a massive system, capable of producing neutron stars and black holes, to a low mass system producing degenerate dwarfs. Very likely the transition is close to 10 solar masses.

Case C of mass transfer is relatively little explored. The primary component becomes a red supergiant and develops a deep convective envelope while filling up its Roche lobe for the first time. In many systems the mass transfer may proceed on a dynamical time scale (Paczynski and Sienkiewicz 1972). Probably, many case C binaries follow an evolutionary pattern similar to case B. However, in low mass systems an interesting phase may precede the second phase of rapid mass transfer. As the binary period is very long the separation between the components is very large, and the secondary becomes a red giant or supergiant before it will fill its Roche lobe. The secondary may lose a lot of

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mass in a strong wind, and part of this matter is intercepted and accreted by the degenerate primary. Once enough matter has been accreted a hydrogen shell may be reactivated and the primary may become very hot and luminous. Symbiotic stars may be in this phase of evolution (Tutukov and Yungelson 1976, Paczynski and Rudak 1979). After some time the secondary will fill its Roche lobe, the rapid mass transfer will proceed for the second time, now in the reversed direction, and very likely a common envelope binary will be formed. In many case C systems the common envelope phase will be encountered already during the first phase of rapid mass transfer, as this mass transfer may be very rapid indeed, proceeding on a dynamical time scale. Of course, some case B binaries may also produce a common envelope already during the first phase of a rapid mass transfer.

According to present ideas about evolution of close binaries all those systems evolve sooner or later into a common envelope configuration. Such a configuration may be imagined as two relatively dense stars moving around each other on a circular orbit and deeply embedded in a low density common envelope. As seen from outside the system may look like a single, relatively rapidly rotating star with two cores. Obviously, the common envelope cannot rotate synchronously with the orbital motion of the two cores. Therefore, there is a drag imposed on the orbital motion, and the two cores gradually spiral towards each other. In this process angular momentum is transferred out from the orbital motion to the rotation of the common envelope. Also, the binding energy of the two cores is gradually deposited into the common envelope. The process may lead either to a coalescence of the two cores or to a loss of the common envelope. In the first case a single star is left. In the second case a binary system is left, but its mass and angular momentum are very strongly reduced compared with an initial state. In some cases the lost envelope may be observed as a planetary nebula with a nucleus which is a short period binary. UU Sge is the best known example (Miller, Krzeminski and Priedhorsky 1976, Bond, Liller and Mannery 1978).

If the common envelope binary was produced during the first phase of rapid mass transfer (from the primary to the secondary component) then the secondary entered the common envelope while on the main sequence. Almost certainly the deep common envelope phase lasts for a short time only, and almost certainly the secondary emerges from that phase being still a main sequence star. The primary entered the common envelope as a star that had evolved away from the zero age main sequence. If it was still burn-

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ing hydrogen in the core (case A) then the initial separation between the two components was so small that coalescence of the two stars is more likely than loss of the common envelope. As we are interested in binary systems, we should consider larger initial separation, i.e. case B or case C of the rapid mass transfer. In that case the primary is likely to emerge from the common envelope stage stripped of its hydrogen envelope down to the helium or carbon core, in the two cases respectively. The binary is now detached and may look pretty much like a binary which did not go through the common envelope phase, except that its mass and angular momentum is very strongly reduced and the orbital period may be very short. In low mass binaries the primary will eventually become a degenerate dwarf, and a system may look like V471 Tau (Nelson and Young 1970). Subsequent evolution may lead to a formation of a semidetached system either because the secondary will evolve away from the main sequence, or because the binary orbit will shrink as a result of angular momentum loss. The loss of angular momentum may be for example due to gravitational radiation or magnetic stellar winds. A semidetached system with a relatively massive degenerate dwarf primary may be identified with a cataclysmic variable, i.e. a nova, a dwarf nova, or a polar (i.e. AM Her type object). Perhaps in some cases further evolution of the system may drive the mass of accreting degenerate dwarf over the Chandrasekhar limit and give rise to a Type I Supernova. If the initial binary had a large mass then the primary component will eventually evolve through a Supernova explosion and will produce a neutron star or a black hole. Subsequent loss of angular momentum and/or a nuclear evolution of the secondary may lead to a formation of a semidetached system, and a low mass X-ray binary. Very likely Her X-1/HZ Her and Cyg X-2/V1341 Cyg are in this phase of evolution.

If the common envelope binary was produced during the second phase of rapid mass transfer (from the secondary back to the primary) then both stars were likely to be in advanced stage of stellar evolution. The two cores embedded in a common envelope are rather compact in this case. They may be either hydrogen or carbon stars, or degenerate cores, or neutron stars or black holes, or various combinations of those. A binary with a low initial mass is likely to produce a pair of degenerate dwarfs. While detached such a system may be very difficult to discover to be a binary. Perhaps some white dwarfs with composite spectra are of this type. When such binary evolves to a semidetached phase as a result of angular momentum loss, it will look like a cataclysmic variable with no

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hydrogen in the spectrum. AM CVn (Smak 1967, Patterson 1979), the shortest period binary known (18 minutes!) is probably of this type. Perhaps some of such systems may evolve to a Type I Supernova. A binary with a large mass is likely to produce eventually a pair of neutron stars or black holes. The binary radiopulsar, PSR 1913 + 16 (Taylor 1979), is the only known system of this type. Very likely, the two compact objects will coalesce at the end as a result of angular momentum loss due to gravitational radiation.

It is easy to imagine that a common envelope phase may be entered by some binaries twice during their evolution. The end product will resemble the product of the common envelope phase produced during the second phase of rapid mass transfer. Probably it would be possible to imagine even more complicated scenarios, but at this stage of understanding of the evolution through a common envelope phase one would not learn much form such considerations. A quantitative and reliable theory of evolution of common envelope binaries does not exist. Not a single common envelope binary has been identified observationally so far. Nevertheless, I believe we can identify observationally and theoretically many types of binaries evolving towards the common envelope stage, and we can identify other types of binaries that have recently emerged from such phase. A few theoretical papers on the subject are available (Webbink 1975, 1979, Paczynski 1976, Ritter 1976, Taam, Bodenheimer and Ostriker 1978, Tutukov and Yungelson 1979, Meyer and Meyer-Hofmeister 1979).

The situation with contact binaries, which have only shallow common envelopes, is much better. A lot of such objects are known as W UMa type systems. Observational data are well summarized and interpreted by Rucinski (1974). Nevertheless, in spite of a large theoretical effort to understand the structure of W UMa systems there is still a controversy over their structure and physical processes within their common envelopes (Shu, Lubow and Anderson 1979, Lucy and Wilson 1979).

The process of mass transfer due to the Roche lobe overflow is reasonably well understood. This transfer is very efficient when one of the components expands over a certain critical surface. If this component rotates synchronously within the binary orbital motion then the critical surface is just the Roche lobe. If this component does not rotate at all then the critical surface coincides with the tidal lobe. The difference between the two is rather small (Plavec 1958, Kruszewski 1963). What is really essential from the evolutionary point of view is the necessity of such critical surface, independent of the rotation law of the expanding component. Once this component overflows whichever surface happens to be critical the matter is free to flow from the stellar surface layers towards the companion. The flow is driven by the pressure gradient through the vicinity of the inner Lagrangian point, L1. If the mass losing star is the more massive of the two, then the rate of flow may be very high. This has been recognized by Crawford (1955) and Morton (1960), but the first detailed model computations were done by Kippenhahn and Weigert (1967). It turns out that if the mass losing star has a radiative envelope then the mass transfer proceeds initially on a thermal time scale. This is the same as the Kelvin-Helmholtz time scale. If the star has a deep convective envelope the mass transfer may even proceed on a dynamical time scale (Paczynski and Sienkiewicz 1972).

Accretion of the transferred matter onto the companion star is reasonably well understood too. If the companion is geometrically small, then a rotating gaseous ring is formed around it, with matter and angular momentum being supplied with a flow from the L1 point (Kruszewski 1967, Lubow and Shu 1975). If there is sufficiently large viscosity the ring spreads into a disk (Lynden-Bell and Pringle 1974). Some matter spirals in and accretes onto the central star. Some matter spirals out and the disk size increases up to the point when tidal forces are capable of removing angular momentum from the outer rim of the disk into the binary orbital motion (Smak 1976, Paczynski 1977, Papaloizou and Pringle 1977, Lin and Papaloizou 1979a). After some time a steady state flow may be achieved, with gas streaming from the L1 point to the outer rim of a large accretion disk, and later spiraling onto the central star. The tidal forces, while capable of removing angular momentum from the outer rim of the disk are inefficient in the inner parts of the disk flow (Weber 1979). Observations show very clearly that some large viscosity operates within the accretion disks. The nature of this viscosity is not known. Perhaps it is due to turbulence or magnetic fields, but no real theory exists. In some systems the disk accretion is responsible for a major part of emitted radiation. It may be so in many X-ray binaries (Shklovsky 1967, Cameron and Mock 1967, Prendergast and Burbidge 1968, Shakura 1972, Pringle and Rees 1972, Shakura and Sunyaev 1973) and in dwarf novae (Bath 1973, Osaki 1974).

The gas spiraling inwards eventually passes through the inner boundary layer and accretes onto the surface of the central star. The accretion probably proceeds through a column or through an equatorial belt. However, if sufficient amount of matter is accreted, then the assumption of spherical symmetry is probably reasonable. The details of a spherical accretion depend on the nature of the central star. Every type of star has a certain maximum rate at which it may digest the accreted matter. This is usually called the critical rate. When the critical accretion rate is exceeded, the excess of infalling matter accumulates in an envelope which builds up around the central core. If a large amount of matter is accumulated the envelope may grow so much that the star becomes a red giant or supergiant. This phenomenom was studied with model computations for an accretion onto a main sequence star (see e.g. Kippenhahn and Meyer-Hofmeister 1977), onto a degenerate dwarf (Paczynski and Zytkow 1978), and in a special case onto a neutron star (Thorne and Zytkow 1977). In all three cases the development of a giant envelope is possible. I would like to emphasize that, contrary to a fairly wide spread belief, there is no reason for the "excess" of matter to be ejected. It is true that once a high luminosity, extended envelope builds up, a mass loss from the surface becomes important, just as it becomes important for any star entering a supergiant phase, no matter what is the energy source in the deep interior. I can see no reason why the accretion process should stimulate a loss of matter accreted at a "supercritical" rate. If anything, one may expect a pressure due to accretion to make the mass loss more difficult. I believe that a "supercritical" disk accretion onto a main sequence star, a degenerate dwarf, or a neutron star also leads to the increase of the stellar radius, therby moving the boundary layer between the disk and the star farther out. Again, there is no reason for a forced ejection of the "excess" of matter. Of course, if the star is a member of a close binary system then a "supercritical" accretion and accumulation of an extended envelope is one of the main reasons for a formation of contact and common envelope binaries.

If the accreting object is a black hole then disk accretion can proceed at a highly supercritical rate without forcing a mass outflow (Paczynski and Wiita 1978, Jaroszynski, Abramowicz and Paczynski 1979, even though the disk luminosity may exceed the Eddington limit (Sikora 1979). Just the "supercritical" disk becomes very thick. A spherical accretion onto and into a black hole can also proceed at a supercritical rate (Begelman 1978). The fundamental difference between the black holes and all other objects is nonexistence of a surface which could support matter. For this reason a black hole is able to digest matter at any rate. Formation of a contract of a common envelope binary with a black hole component may be somewhat more difficult than it is with other components.

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It is well established observationally that binaries lose mass and angular momentum, i.e. their evolution is "non-conservative" (Ziolkowski 1979). Single stars are also observed to lose mass and angular momentum. There are many theoretical suggestions, and many mechanisms proposed to explain the observations, but there is no theory which could permit quantitative evaluation of mass and angular momentum loss from either single or binary stars.

A large fraction of a binary mass may be lost in explosions, through a common envelope, or through a wind (Ziolkowski 1979). Angular momentum may be lost through the gravitational radiation, magnetic winds, mass outflow through the outer Lagrangian point L2, excretion disks, and through a common envelope. Other possibilities must certainly exist as well. I shall discuss now the possibilities listed above.

Gravitational radiation leads to a loss of angular momentum on a time scale

$$T_{collapse} = 10^7 \text{ years } \frac{(m_1 + m_2)^{1/3}}{m_1 m_2} \left(\frac{P_{orb}}{1 \text{ hour}}\right)^{8/3}$$

where $m_1 = M_1 / M_\odot$, $m_2 = M_2 / M_\odot$.

This may be important for the evolution of cataclysmic variables novae, dwarf novae and polars, and W UMa stars (Paczynski 1967a), but probably other modes of angular momentum loss are more important. The binary radio pulsar PSR 1913 + 16 (Taylor 1979) is the first system in which the effect of gravitational radiation has been observed.

Magnetic wings were suggested to be important for a loss of angular momentum from rotating single stars (Schatzman 1962) and from binaries (Mestel 1967). This effect may be very important, but quantitative estimates require a knowledge of the wind mass loss rate and the strength of stellar magnetic field. Both parameters may be found only from from observations of particular systems.

Mass outflow through the outer Lagrangian point L2 was studied by Kuiper (1941), and most recently by Shu, Lubow and Anderson (1979). For this process to be important the envelope of a binary must rotate synchronously with the orbital motion. Otherwise the L2 point has no dynamical significance. In the case of synchronous rotation the mass flowing from L2 carries out at least ten times more angular momentum per unit mass than the average value for the binary. As result the binary size decreases dramatically while only a small fraction of the total binary mass has been lost. This limits the usefulness of this mode of outflow for losing a large amount of matter, but makes it a very efficient sink of angular momentum (Ziolkowski 1979).

Excretion disk may form around a whole binary as a result of the mass outflow from L2 (Webbink 1976, Shu, Lubow and Anderson 1979, Lin and Papaloizou 1979b). Once formed, an execretion disk may remove practically any amount of angular momentum from the binary by means of tidal effects. In this process very little or no mass loss is necessary. This is a potentially very efficient and practically unexplored mode of angular momentum loss. Very little, if anything is known observationally about the excretion disks, including their existence.

Common envelope is a very efficient mode of angular momentum and mass loss from a binary. I have already emphasized that there is little theoretical knowledge about common envelopes, and no direct observational information about such objects. It would be very important if some red giants or supergiants were discovered to have excessively large rotational velocities. Such stars could have double cores, i.e. they could be the common envelope binaries. A search for close binary nuclei of planetary nebulae would also be very important (Paczynski 1976, Miller, Krzeminski and Priedhorsky 1976, Bond, Liller and Mannery 1978, Acker 1978, Lutz 1978).

At the end I would like to discuss one of the puzzles of the X-ray systems. Evolution of massive X-ray binaries is reasonably well understood (Ziolkowski 1977). However, the so called galactic bulge X-ray sources are not understood. This class includes also bursters, globular cluster sources, Sco X-1, Cyg X-2 and many others. According to Lewin and Clark (1978) these sources are characterized with "soft" X-ray spectra, variability on time scales of minutes to days, luminosities in excess of 10 xx 36 ergs per second, no periodic pulsations and no eclipses. The observed ratio of X-ray to optical luminosity is about 1000, but practically no "reflection" effect is seen from the companion. One may wonder if they are binaries at all? To avoid obvious photometric difficulties Milgrom (1978) and Joss and Rappaport (1979) suggested that X-rays are produced by means of disk accretion onto a neutron star or a black hole. The disk is supplied with matter by a low mass main sequence star through a Roche lobe overflow. The disk is optically and geometrically thick to shield the main sequence companion from the X-rays. The system could be seen as a strong X-ray source only if viewed from above or below the orbital plane, because of the high anisotropy of radiation. Recent observations of Cyg X-2 (Cowley, Crampton and Hutchings 1979) demonstrate that this is a binary with a period of 9.8 days. Optical light curve shows strong tidal distortion but practically no reflection effect, while the ratio of X-ray to optical luminosity is 250:1. Clearly, the X-ray emission is highly anisotorpic, as postulated by Milgrom, Joss and Rappaport.

If galactic bulge sources are binaries, how could they form? Clark (1975) and Fabian, Pringle and Rees (1975) suggested that globular cluster sources formed by capture. If this is true then other types of binaries should form by capture as well. Indeed, there are claims for a presence of novae and dwarf novae in globular clusters (Trimble 1977). These are probably composed of a degenerate dwarf and a main sequence star. But what about pairs of main sequence stars? None have been observed. However, there is an old problem of blue stragglers, stars which are located on the extension of the main sequence above the turn of point on the H-R diagram (cf. Johnson and Sandage 1956 for a color-magnitude diagram of M3). According to McCrea (1964) these stars are binaries. This hypothesis got some observational support from Strom and Strom (1970), but perhaps because of some conflicting observations the problem has not been much studied recently (but see Wheeler 1979). I would like to point out that the binary nature of blue stragglers may be of importance for the problem of globular cluster X-ray sources, and possibly all the bulge sources. It may well be, that even if blue stragglers were very close binaries some time ago they could have coalesced by now. In that case they should be rapid rotators.

There are certainly many new objects and processes to be discovered in the realm of close binaries. These systems may help us to understand the accretion processes onto compact objects, formation of symmetric radio lobes (like in Sco X-1), and production of hard X-rays (like in Cyg X-1). All these phenomena are observed on a much larger scale in active galactic nuclei, radiogalaxies and quasars, but they may be easier to study in nearby eclipsing binaries. The binary radiopulsar PSR 1913 + 16 (Taylor 1979) may provide the first demonstration of general relativistic effect which goes beyond the post-newtonian approximation (gravitational radiation). Finally, we may find entirely new and unexpected phenomena, like the most spectacular object SS433, which very likely is a close binary system. Clearly, the future of binary research looks exciting for the observers and theorists alike.

At the end of this presentation I would like to appologize for ignoring a very exciting subject: disk structures in Algol and Beta Lyrae type systems. Over the past ten years or so a very large number of papers was published on this subject. The disks are readily seen spectroscopically as well as photometrically, they affect the eclipses and produce intrinsic polarization of starlight, they vary on time scale of years and even months. Unfortunately this vast amount of observations and interpretation of observations has never been reviewed or summarised, as far as I know. I was personally unable to follow those most interesting results of D. S. Hall, M. Plavec, R. E. Wilson, and many others, carefully enough to present a competent summary of their work here. I hope that somebody will undertake this task soon.

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