INTRODUCTORY ADDRESS

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Some time ago my good friend Mirek Plavec wrote to me saying that since I was the senior in the Organizing Committee of this Symposium on the Structure and Evolution of Close Binary Systems, I should be in charge of the Introductory Address. And this is how and why I am here before you trying to fulfill the task of raising the curtain of the stage where so many important current problems in the field of close binaries are going to be discussed.

We are living in a very demanding and flourishing time in our domain of research. The observational results and the ideas that are being proposed almost every instant have set the subject in such a state of flux that this meeting that was originally planned as a small colloquium to discuss problems related with contact binaries soon developed into a fully-fledged symposium where a wider range of questions was to be thoroughly examined.

During the last twenty years we have witnessed an explosion – let us call it a 'constructive explosion' – in the number of astronomers and physicists engaged in our field and, consequently, to an explosion in the number of papers that we are subjected to in almost every issue of every astronomical journal and in some non-astronomical journals as well. And the progress has been steady and there has been quite a number of very important contributions from which I would like to enumerate those that, as far as I remember, can be considered as the main landmarks that border the road so magnificently opened by Otto Struve, namely,

(a) Crawford's suggestion, in 1956, to account for the Algol paradox;

(b) the recognition that the spectroscopically visible member of a close binary could be less massive than the fainter or invisible companion (Sahade, 1958a, b; Sahade *et al.*, 1959);

(c) Walker's discovery of Nova DQ Her as a binary system and the subsequent investigation of the old novae by Kraft;

(d) Huang's suggestion of the existence of a thick, flat envelope (disk) surrounding the secondary components in ϵ Aur and in β Lyr;

(e) the computation of models of close binary evolution;

(f) Smak's suggestion of the existence of hot spots in the circumstellar envelopes of cataclysmic variables;

(g) the application of new observational techniques, like high-time-resolution photometry, radio interferometry, etc;

(h) the discovery of X-ray binaries.

In regard to point (e), the computation of models of close binary evolution, a further, realistic step, already suggested several years ago, and now more generally advocated,

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P. Eggleton et al. (eds.), Structure and Evolution of Close Binary Systems, 1–8.

most specially by Plavec (1973) is being taken. I am referring to the realization (a) that the computations should consider non-conservative cases, and (b) that the evolution of the companion to the star that is losing mass should also be looked into. It would also be desirable to come to describe the atmospheres of the components because the matching of theory with observations only in regard to the position in the H-R diagram does not seem to be sufficient, specially when we are dealing with such bizarre objects as the ones that result from the evolution in close pairs.

In this explosion of interest and output I sometimes feel that we are in too much haste to provide models and to reach definitive conclusions when the phenomena to be explained are not simple and, in most cases, the amount of available information is too meager even to attempt a simple description of the actual facts. One could mention as an example, the question of the transition in the X-ray spectrum of Cyg X-1 which was observed in March of 1971 with apparently no further changes ever since. Only recently additional observations disclosed the possibility that the so-called 'high state' is a repeating phenomenon that may last for only some 20 days or so (Sanford *et al.*, 1975) and may be connected with changes in the accretion rate.

At some times I feel that in our haste we tend to forget some basic facts of life. I am thinking, for instance, of the question of the masses. It is unfortunate and at the same time challenging that whenever we have a very interesting system no possibility seems to exist of determining directly the individual masses. And then one turns to different procedures to try to derive their values in the hope that these values would be meaningful and would permit the building up of a sound model. But I am not sure that they always are nor I am sure that we always keep in mind the uncertainties that affect the results or how useless these are in, shall we say, a large number of cases.

Many years ago it was thought that every star obeys the mass-luminosity relation, something that we now know is only true on the main sequence. Such a belief was so strong that it was very successful in preventing progress in the understanding of a system like β Lyr during more than fifteen years, because it was out of the question then to think in terms of a fainter or invisible star being more massive than the brighter component.

The assignment to a star of the mass that would be normal for the spectral type concerned seems reasonable if we are dealing with objects that are on the main sequence and have not undergone any mass loss during their lives. But, even on the main sequence, the well determined masses are not larger than about thirty solar masses (Batten, 1968) and, even in some cases that fall within this range, and indeed for larger masses, the determination of the individual values is only possible after some necessary interpretation of the velocity curves and, in the corresponding systems, one could only talk about the order of magnitude of the masses and/or whether the mass ratio is larger or smaller than one. There are no mass determinations of early type supergiants and the best masses of supergiant stars correspond to spectral type K. The most luminous early-type objects for which there are masses available are a B1 III star, which belongs to a system that does not eclipse, and an A2 II object; the masses are of the order of five solar masses. For lack of the proper information, is it admissible, or even reasonable, to assign to a component which is off the main sequence the mass that is suggested by the evolutionary tracks of single stars computed on the assumption that there has been no mass loss during their evolution? Over- and underluminosity are common features among components of interacting binaries and therefore the answer is obvious. The procedure seems to be as bad, or maybe even worse, if we are dealing with a system which is undergoing mass outflow for the second time. A case that comes to the point for this question of adopting mass values is the case of BD +40°4220. BD +40°4220 is a system formed by two Of stars of equal luminosity (about −7.1 in the visual) and yet the mass-ratio is a little over four, according to a forthcoming paper by Bohannan and Conti (1975). Are we dealing with two *bona fide* Of stars or, as happens in some systems like HD 47129, does the spectrum of the secondary component simply mimic the spectrum of the primary? In either case, the example illustrates my point. And since we talk so much about β Lyr, let us remember that the luminosity class of the spectrum of the principal component corresponds to an absolute magnitude that agrees with the distance of the object and it is almost certain that the star is overluminous for its mass.

Another rather appealing way of computing masses or mass ratios is by considering the Roche geometry on the assumption that one of the components fills *exactly* its Roche lobe. The procedure has been shown (Sahade and Ringuelet, 1970) to yield results that may be wrong by a very large factor; its application led to the 'discovery' of the existence of groups of objects, like the once so-called R CMa stars, which later were proved not to be real.

Besides the question of the masses there is the question of *UBV* photometry, which is not exactly the most appropriate photometry to deal with very peculiar objects, and this is something we tend to forget sometimes.

At this point perhaps you would like to pose to me the question that is asked in a famous Brazilian series of cartoons, namely, as to whether I am your friend or a friend of the tiger. I am just trying to say that it is good to analyze a problem, and consider all the possible answers utilizing all the permissible means but that we should state and keep in mind the limitations that we are confined by and the implications of each possibility; and, above all, that we should try to gather as much observational information as possible on the object concerned, covering simultaneously, if at all feasible, as wide a range of energies as one can, before attempting to engage in the definitive solution. I like to use the word 'definitive' because on one occasion – it was a meeting of the American Astronomical Society – two consecutive papers that were concerned with the 'definitive' model of β Lyr were presented . . . and that was several years ago.

If you allow me to use the opportunity of this introductory address to make a few more comments rather than to try to summarize what has been done in the field since the Parksville Symposium in 1972, which is too close in time to this one, or to bring about a few recollections related to the field, I would like first to say, since I just mentioned β Lyr, that although we still do not know all the answers in regard to this peculiar system we have made some progress towards its understanding and some very interesting suggestions have been advanced concerning the secondary component. We were hopeful – perhaps I should say unduly hopeful – that observations in the ultraviolet would finally disclose the nature of such a component, but they simply confirmed the model that postulates the existence of a thick flat envelope around the invisible companion. However, recent but not yet published work (Hack *et al.*, 1975), based on observations made with the ESRO TD-1A satellite through experiments S2/68 and S59, have added some new information. These observations, combined with Kondo *et al.* (1971) light curves, have suggested that the Fe III emissions originate within the expanding outer envelope where the shell lines are formed, while the emitting region of C IV, and perhaps Si IV, are located in the circumstellar envelope that surrounds the secondary component. The flat thick disk must thin out in all directions and form perhaps a spherical envelope, not necessarily with the same nor with constant density gradient in all directions. Furthermore, the emissions that are observed in the ultraviolet suggest that they are collisionally excited. It may be that further combined observations will permit a more thorough analysis of the characteristics of the circumstellar envelope that surrounds the secondary component and perhaps, through our knowledge of the envelope, we may be able to infer some conclusions in regard to the star itself.

I think that β Lyr is certainly the star that has been the subject of the largest number of investigations. And although there is always quite an interest in making contributions that will help in reaching an understanding of the system, at present the X-ray binaries, and in particular Cyg X-1, are great competitors.

I am not saying anything new if I say that the main importance of Cyg X-1 lies in the fact that it is considered *the* case providing observational evidence for the presence of a black hole in the system. This belief is rather strong generally and, as the result, in a meeting held two years ago, the year 1973 was declared the year of the black hole. I must admit that all the lines of reasoning used point in such a direction but I am not quite certain that all the reasonings are solidly based.

Unfortunately in Cyg X-1 again we have no direct information about the masses of the components of this object that must be undergoing mass outflow for the second time. We know that the optically visible component, a B0 Ib star, according to Hutchings *et al.* (1973), describes an orbit in about five and a half days, and we know that the system is characterized by a rather small mass function, namely, $0.23\mathfrak{M}_\odot$ (Brucato and Kristian, 1973; Brucato and Zappala, 1974). I have already made remarks that apply in this case and so, in regard to Cyg X-1, I would just like to bring out a few points that deserve further and more thorough investigation.

As we all know, the spectrum of HDE 226868 is characterized by the presence of emission lines, at least at Hα, Hβ and He II 4686. The He II emission must originate, as Smith *et al.* (1973) and Hutchings *et al.* (1973) have shown, in a gaseous stream that goes from the supergiant star towards the X-ray companion. The earlier suggestion of Smith *et al.* (1973) was beautifully confirmed by Hutchings *et al.* (1973) whose velocity curve from the He II emission was phase shifted by some 120° with respect to the velocity curve from the blue supergiant, which, in turn, suggests, as would be expected, a stream directed towards phase 0.5–0.6 P, counted from superior conjunction, with a velocity of the order of 150 $(\sin i)^{-1}$ km s^{-1}.

In regard to Hα, Brucato and Zappala (1974) have found that this line displays double emission and that there are variations in intensity and width of the components. In June, July and August, 1973, the blue component was very weak or absent in the phase interval that goes between approximately 0.6 and 0.2, while in December of the same year this was not so and the absence of the blue component was noticed on a plate taken at about phase 0.5. The velocities from the emission components are scattered over some 100 km s^{-1} but they do not seem to suggest orbital motion nor is the observational material enough to tell whether there may be some kind of periodicity or quasiperiodicity involved. The average velocities that are suggested are of the order of +200 and −220 km s^{-1}, respectively.

It is difficult to locate the source of the Hα emission without having more information

https://doi.org/10.1017/S0074180900011797 Published online by Cambridge University Press

on the behaviour of the feature along several cycles and of the actual profile characteristics. The emissions do not seem to originate in the stream nor it is clear whether it is associated with the circumstellar envelope around one of the components or whether we are dealing with an outer, large envelope surrounding the whole system. At any rate, it would seem as though the decrement is rather steep, which, in turn, would suggest that the line or lines are produced in a thin envelope. Now, are we actually dealing with two emission components, or is it only one emission profile cut by the absorption line of the spectrum of the B supergiant and modified by some variable phenomenon in the system? Does Hβ behave in the same way?*

I have mentioned the possibility of some variable phenomenon in the system. In the recent COSPAR meeting in Varna, results of the observations of Cyg X-1 with the ANS satellite were reported by Parsignault *et al.* (1975). They confirmed previous results and further suggested that there exists a 45% chance to observe a decrease in the X-ray flux intensity (the observations refer essentially to the energy range 1.4–7.0 keV) of the order of 50% of the quiescent value. During these dips, which have been observed with the ANS satellite at phases 0.00, 0.085 and 0.16, the X-ray spectrum of Cyg X-1 became harder. Much less conspicuous dips seem to be present at other phases during the same cycle, and the times of duration appear to be different in each case. Parsignault *et al.* (1975) believe that the observed changes in X-ray intensity are most probably due to an absorption phenomenon produced by a non-permanent feature related with the gaseous stream rather than to a decrease in the power output of the object. This interpretation implies that the physical condition of the stream or of the matter between the two stars is strongly variable and that this shows principally when we look at the system at or immediately after superior conjunction. If this were so – and something similar seems to be true in the Wolf-Rayet system CV Ser (Schild and Liller, 1975) –, a more thorough analysis of the behaviour of the X-ray intensity flux of Cyg X-1 during several cycles may throw some light on the physics of the mass outflow and/or mass transfer between the two stars and perhaps give some further insight into the actual nature of the X-ray component.

Since the He II 4686 and the Hα emissions appear to display variations during the cycle and/or in different cycles, and since there seem to be drastic changes in the blue shifted component of Hα at a phase interval which appears to be centered at about superior conjunction, it would be extremely desirable to carry out a simultaneous investigation in different ranges of energy, including, of course, the photographic region of the spectrum, to try to disclose the nature of the observed variations and also decide whether at times at least there may be any contribution to the continuous spectrum of HDE 226868 from the variable stream.

I should further recall what I said earlier in regard to the problem of the 'high state' and the 'low state' of the X-ray spectrum of Cyg X-1 and report that in May of this year a drastic increase in the mean density flux at 8.085 MHz was detected, the observed value showing a variation over a period of five hours of observing (Hjellming *et al.*, 1975). This information emphasizes even more the pressing need for simultaneous observations, as far as feasible, in the widest possible energy range, and the fact that such observations should

* In a paper which I overlooked when writing this Address, Hutchings *et al.* (1974) suggested that "the emission arises in an accretion ring surrounding the X-ray source", but as the authors rightly pointed out "high quality Hα observations appear to be highly desirable".

be carried out for a rather long period of time even if there are no immediately rewarding results. For the sake of completeness, perhaps I should at least mention the question of the short time variability of Cyg X-1, which is not yet clearly understood and for which the knowledge of the energy spectrum is still open, as far as I know.

I am not going to touch upon other X-ray binaries except to say that I was quite interested to read that Lyutyi *et al.* (1974) have been able to describe Sco X-1 as a binary system of a period of nearly four days where the primary component is a late type subgiant, a fact that, therefore, would mean, as Illarianov and Sunyaev (1975) have pointed out, that there would be now two types of X-ray binaries, those whose primaries are early type supergiants and those whose primaries are late type subgiants. Her X-1 and Cen X-2 would be members of the latter group. If Lyutyi *et al.* are right, then the whole picture of the X-ray sources becomes more complete and we would have at hand an additional piece of information for our endeavours in the field of binary evolution. Hutchings has been able to show that the actual period of Sco X-1 is of the order of 0.7 day. Let me finish this reference to Lyutyi *et al.* (1974) paper by adding that again in Sco X-1, He II 4686 seems to yield a velocity curve phase shifted with respect to the velocity curve of the visible companion, but the shift is such that it cannot be understood in terms of a gaseous stream towards the X-ray companion but rather in the opposite direction. If this result were confirmed, the situation would be most exciting.

Another comment I would like to make is in regard to the Wolf-Rayet stars, which are not specifically mentioned in the program, but will appear, I am sure, somewhere during some of the presentations. Conti (1975) has just suggested at the Liège Colloquium held last month, that O stars evolve into Of objects and these into Wolf-Rayets, a scheme that, incidentally, is very interesting to me because it is just the reverse to the one I happened to suggest nearly twenty years ago (Sahade, 1958c). In Conti's ideas, the transition stage between the Of's and the Wolf-Rayets, or perhaps I should say the first appearance of a Wolf-Rayet spectrum during the evolution is as a WN7 object because the spectral characteristics of the WN7 stars appear to be closer to that of the Of's than the rest of the Wolf-Rayet objects. Furthermore, in a forthcoming paper on the orbit of BD +40°4220, a system I already mentioned, Bohannan and Conti (1975) suggest that the secondary component is on the way to becoming a Wolf-Rayet star.

Now, rather recently, Niemelä (1974) has finished the study of a southern WN7 star, namely HD 92740. This object has relatively strong H and other absorption lines, and if we adhere to the usual reasoning that whenever H and other absorption lines are present in a WR spectrum we must be dealing with a binary describable as a WR + O-B system, HD 92740 ought to be a double line binary. However, in this case radial velocities were measured and the conclusion is that indeed we are dealing with a binary, but with a single line binary, the H absorptions yielding a velocity curve which agrees with that of the WR star in amplitude and in phase. The photographic region seems to offer no information on the other component; however, Henize *et al.* (1975) have reported at the COSPAR meeting held last month, that the companion in HD 92740 – as well as in two other WN7 stars, namely, HD 151932 and HD 93131 – tends to dominate the ultraviolet spectrum obtained on the Skylab.

It is interesting to point out that also in θ Mus, a WC6 + O9.5 I system, and perhaps in γ^2 Vel, a WC8 +O7 system, two stars which, incidentally, in Allen and Porter's (1973) near infrared photometry of southern Wolf-Rayet stars were found to be significantly bluer than other members of their class, the spectrum of the companion dominates in the ultraviolet.

Although Conti may be right in his evolutionary ideas about the Wolf-Rayet stars, the possibility still remains that the conclusion to be drawn from the study of HD 92740 may be different. It may be that in general the H lines arise at least partly in the Wolf-Rayet component and, if this were so, we may have to change the current generally accepted ideas about masses and chemical composition of Wolf-Rayet stars. Only further investigation or reinvestigation will give the answer, and this is another area where information from different energy ranges will be most far-reaching.

As you know, the near infrared survey of Wolf-Rayet stars (Allen *et al.* 1972; Allen and Porter 1973) has brought up the problem of explaining why the WC stars are systematically redder than the WN objects, and, furthermore, why the WC9 stars are so highly reddened. Is it a question of the composition of the material ejected by the objects or is the meaning quite a different one? And, why are γ^2 Vel and θ Mus much bluer than the rest of the WC stars? Is this fact simply the result of the nature of the O companions?

Another area which is not specifically mentioned in the program is that of the symbiotic objects. Since I am being already too long I will only say that the extension of the observations of the symbiotic stars into the near infrared and radio ranges of energy, and the study of the so-called BQ [ ] stars, have brought forward the existence of two main types of symbiotic objects, namely those with no dust emission and those with dust emission; and among the latter, some of which have been found to be radio sources, we have the so-called yellow type and the objects with high excitation spectra found by Webster and Allen (1975). The information available about the symbiotic stars seems to suggest that at least some planetary nebulae may result from the evolution of the former objects (Sahade, 1975; Mammano and Ciatti, 1975) but further work is needed to pin down this possibility. Unfortunately, here again so far there are no reliable mass determinations of the components of symbiotic objects (cf. Sahade, 1975).

In studying the system of AG Peg, Hutchings *et al.* (1975) have suggested a model which is opposite to the one generally accepted for the symbiotic stars and also to the one that was derived from the investigation of AR Pav (Thackeray and Hutchings, 1974; Andrews, 1974). This question is an important one, and the answer should be sought through a new investigation based on material providing a good and more compact coverage in time of the orbital cycle or, even better, of a few cycles.

I am not going to be much longer since you all must be anxious that I finish so that we can start the actual papers. Let me only add that this meeting is perhaps the first one on close binaries where some very specific interrelated problems are going to be discussed at length, and it is taking place almost at the same time as the Symposium in Cape Cod where the problems relating to the possibility of some Be objects and all shell stars being binaries will be taken up. The field of close binaries is now, as I have already said at the beginning, as lively as never before. And to add to the excitement we have the relatively recent discovery of the pulsar binary PSR 1913 + 16 by Taylor and Hulse (1974), and of the new eclipsing binary in the Trapezium, υ^1 Ori A, by Lohsen (1975). The pulsar binary, about which we will soon hear some information in the soft X range of energies from observations with the ANS satellite, will be discussed this morning and therefore I do not need to say anything at this occasion.

I am sure that this Conference will be a very successful one and will add a great deal to our understanding of the evolution of close binaries and to the mechanisms of mass outflow. Perhaps even some combined efforts could result towards a more thorough investigation of the more puzzling objects. I look forward to hearing the discussions and also look forward to the new input that will result from EUV observations of dwarf novae during the Apollo-Soyuz Test Experiment, and to the avenues that will open up when the IUE satellite and the Space Shuttle will be operational.

This paper was written when I was enjoying the hospitality of the Institut d'Astrophysique in Paris, and it is my pleasure to record my appreciation to its Director, Professor Jean-Claude Pecker.

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