SUMMARY

JORGE SAHADE*
Instituto de Astronomía y Física del Espacio, Buenos Aires, Argentina

I have been assigned the task of presenting a summary of the Conference that has just finished. Actually during the Symposium the review papers have touched upon many items, some of them apparently not strictly connected with the subject of the meeting but helpful to clarify the picture related to close binaries and aimed at establishing differences with single stars, whenever possible. Therefore, my task would be somewhat difficult it if were not that all the review papers were extremely clear, very well given and fully discussed and that there were so many contributions from the floor presented without any pressure from time or otherwise. Furthermore most of what I would say has been already said. All this makes my task a lot easier as it appears clear that I should confine myself to offer only a few comments. Let me start by saying that Dr. Struve would have felt most pleased to have been present at this meeting and realize how many astronomers are now interested, strongly interested, in the field of close binaries and how much the field has and is expanding taking also up the efforts of researchers that work in the radio and X-ray regions and attracting the attention of those who are interested in problems of general relativity.

The interest in the field, at Struve's time, was so extremely limited that in 1957 I made in the *Publications of the Astronomical Society of the Pacific* an appeal to photoelectric observers to engage is some cooperative programs that required an urgent and simultaneous attack from the photometric as well as from the spectrographic side. No reply was received. How different things would have been ten to fifteen years later!

From the observational point of view the Conference has summarized our present knowledge in regard to the structure commonly found in interacting binaries with the presence of gaseous streams usually coming from the less massive component of the system, with the presence of gaseous envelopes around one of the components – usually around the star towards which the gaseous stream is directed – and with the presence of outer, more tenous, envelopes that surround the whole system.

Observational evidence has been presented that adds to the one already available and confirms the existence of an interaction between the stream and the gaseous envelope around one of the components or perhaps in some cases with the star's outer layers, depending partly on how thick or thin the envelope is. The result of this interaction has been described with the terminology of 'hot spot' – the fourth element in the structure of circumstellar matter – and whenever the conditions, velocity of the stream, density of the envelope, are appropriate, it gives rise to the production of X-radiation in the soft range of energies.

We have been further given the observational facts – some recently secured –

* Member of the Carrera del Investigador Científico, Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina.

Batten (ed.), Extended Atmospheres and Circumstellar Matter in Spectroscopic Binary Systems, 286–291.

related to stars – either single or binary – with expanding and with extended envelopes.

From the theoretical point of view we have been exposed to up to date information as to the state of the art in regard to the points touched in the observational reviews. They were clear in stating the difficulties of the problems and the present possibilities.

The last review paper presented the evolutionary pictures that are now available for close binaries and made use of them to suggest an explanation for some specific objects.

Our Conference has been very fruitful in bringing together a good number of research workers in the field of close binaries and provoking some interesting discussions such as the ones that referred to the period changes and to the problem of dealing with contact configurations.

However, no new discussion has been made related to the physical conditions, to the parameters that characterize each one of the elements of the structure of the circumstellar matter in different objects and/or types of objects, to the physics of mass outflow and of the whole process of mass exchange.

From the observational point of view we have to give the theoreticians the values of the parameters that characterize the present configuration of a close binary including information on everything which is there in addition to the stars in order that the comparison between theory and observations be more meaningful.

Following this line of thought, quantitative spectrophotometric measurements have been programmed for β Lyrae in order to try to understand something about the phenomena involved and to find a correlation, if possible, between the amount of mass being ejected from the primary component, the intensity of the emission lines, the variable features in the velocity and light curves and the amount of material that occupies the expanding envelope that surrounds the whole system.

Quantitative measures of the kind are badly needed and should be carried out in as many selected systems as possible. Particularly through Struve's pioneering work, which has provided us with a qualitative understanding of close binary phenomena, we know which systems deserve preferent and systematic attention. The problem is not simple but the outcome will certainly be rewarding.

In particular, spectrographic and photometric observations should be made simultaneously, should cover as long an interval of time as possible with a good coverage of one cycle and of different cycles, photometry should be done with interferometric filters in appropriately chosen wavelengths to avoid contamination with emission features, the coverage in energy range should be extended so as to obtain information in several energy ranges.

In this way we may perhaps come to understand systems like W Serpentis the light curve of which has defied so far an interpretation and whose spectrum in the photographic region does not give information about either star.

For the extension of the range in which observations of particular objects ought to be made, let us hope that Anne Underhill will succeed in including among the NASA projects a satellite with adequate instrumentation that will help to solve or gather more information on different problems. Perhaps a resolution from this Conference might be helpful.

Another important point is the following. Research on several types of peculiar objects has disclosed in many cases that the peculiarity can be traced to and explained in terms of the binary nature of the objects. There certainly must exist quite a number of additional peculiar objects that if investigated adequately will prove to be binaries and will extend our knowledge and help our understanding of evolution of close binaries. The stars that were discussed by Mrs. Peters and by Anne Underhill are two promising cases that may open new avenues of research in the field of peculiar close binary objects.

In this context Plavec's suggestion of some shell stars being perhaps binaries is to me a very good one. We have been studying peculiar binaries that show readily to be so for their velocity and light characteristics. But there certainly must be a number of binaries whose nature will be perhaps only disclosed after careful analysis of the spectral behavior as the characteristics – mass outflow and interaction – connected with the particular stage of evolution in which they are may mask or distort the stellar features in a very drastic way.

Perhaps I should remind you that to me – I know that somebody in this room may disagree with me – there is a fairly good evidence that suggests that the V/R variables are binaries with periods of a few hours. The components of such systems must be very different from main-sequence stars.

We used to say that the evolution of close binaries must be different from the evolution of single stars. And we are finding more and more objects that confirm that statement.

The secondary components of β Lyrae, V 453 Scorpii and ε Aurigae must be very peculiar objects indeed that find no counterpart among single objects. They are probably massive, more massive than the primaries, relatively small and are surrounded by thick envelopes. Suggestions have been made that they are black holes. It would certainly be terribly important to find evidence for black holes and in the case of close binaries we should be looking for at least two of the indicators that go with a black hole, namely, X-radiation and the particular type of light variation at primary minimum if there is no thick envelope around the black hole or the inclination is adequate. Neither of the three objects are known to be X-ray sources but they should be tried at different phases and particularly within the phase interval where we may expect to observe the stream colliding with the circumstellar envelope.

At the Elsinore Conference on Close Binaries I mentioned the three epochs we can distinguish in the study of close binaries. We could perhaps add the present epoch which seems to be characterized by a haste in trying to be the first one in identifying a black hole (black holes are stylish today as magnetic fields were some years ago) and, as a result, too many stars have been assigned to black hole identifications. It is very good to point out the possibility but one should try to see whether other alternatives are possible.

Going back to the objects I just mentioned, let me remind you that the spectrum of the secondary component of V453 Scorpii displays only emission lines that shift in antiphase with respect to the absorption lines from the primary star. The spectrum of

the secondary component of β Lyrae may behave the same way. It did so at the time of Belopolsky and of Curtiss but at present the emission certainly comes from different sources and the interpretation of the feature is still not totally clear; the investigation under way by Batten and myself may clarify the situation.

In the same context, let me say that Hutchings' interpretation of the spectrum of the star from the surroundings of which the X-radiation of Cygnus X-1 comes from is very important. Such a spectrum appears to be quite similar to the one of the optical counterpart of Sco X-1 which, in turn, looks similar to that of a WR object and has been described as similar as that of an old nova.

It is just possible that we may be dealing with similar – not identical – kind of objects in the case of Cyg X-1 and of V453 Sco, although the mass assigned to the peculiar component of V453 Sco is much larger than in the case of Cyg X-1, if my memory is not failing me. Further investigation on the two objects is certainly needed.

In his talk Plavec gave arguments against the identification of some components of close binaries as black holes, and other arguments could still be added in certain cases, such as the need for a hot star, in the case of β Lyrae, to provide the excitation required to produce the emission lines of H and He I.

No reference has been made in this Conference to the fact that in double-lined early type binaries it is sometimes found that at least part of the envelope emits continuous radiation which veils the stellar lines of the star surrounded by the envelope giving rise to the phenomena of variable line intensity known in systems like UW Canis Majoris.

The complications in the light curve of W Serpentis, which appears to have some similarity with that of HD 187399 presented during the Conference, may find their explanation in the presence of a thick envelope around one of the components. After all the spectrum of W Serpentis is essentially a shell spectrum as it is the case in V367 Cygni.

The idea of the 'disk' as suggested by Huang for β Lyrae and ε Aurigae has provided a word which seems to be adequate for describing the rather flat circumstellar envelopes surrounding one component in Algol-type and other systems. But in objects like HR 2142, if Mrs Peters interpretation is correct, the circumstellar envelope must not be flat but occupy quite a volume. Similarly, in Wolf-Rayet stars, a large percentage of which – perhaps even 100% – are binaries, the envelope where the WR spectrum is formed must surround the whole star. For this reason, I prefer not to use the word disk to describe one of the elements of the circumstellar matter around binaries but to call it simply 'circumstellar envelope', disk being a particular case of such envelopes.

In regard to the 'outer envelope' (Batten's cloud), mention has been made in this Conference, of the densities involved. However, there are cases like those of υ Sagittarii and W Serpentis where forbidden lines appear in the spectrum, and that of γ_2 Velorum in the UV spectrum of which there appears an intercombination line displaced the same amount as the shell lines of He I; in these cases the densities of the outer observable layers of the envelope must be much lower, of the order of 10^6, as in the symbiotic stars.

Perhaps because a short reference was made in a Conference four years ago no mention has been made here to the existence of expanding envelopes around close binaries and the velocities involved. Here again figures on the rate of mass loss should be highly desirable as we keep repeating one or two values which were estimated several years ago.

Typical velocities of the expanding envelopes are near 200 km s^{-1} in the case of β Lyrae, 300 in the case of υ Sagittarii, 700 in the case of HD 47129 and 1300 km s^{-1} in γ_2 Velorum.

By the way, mention has been made in one of the sessions of the importance of radiation pressure in defining the motion of the stream. HD 47129 provides a good example of such a fact, as in such case there is a strong deflection of the stream away from the O star.

In the course of the Conference a suggestion has been made for the existence of stellar 'lumps'. Hall's suggestion seems to be difficult to accept and it appears preferable to think in terms of colliding streams. But in order to be able to decide or to come to a different interpretation one has first to know more about the observational facts, particularly, the behaviour with time of the feature that has been interpreted as indicating a possible 'lump' in the star.

I mentioned that I found the discussion on period changes extremely interesting. Let me add that I thought that Hall's model sounds very promising. But the idea should perhaps be checked by trying to see whether there is any correlation with the density of the circumstellar envelope as suggested by the spectra in each particular case.

Since Struve's time we have made quite some progress in our knowledge of close binaries through more refined photometric techniques, through the computations related to evolution, through the discovery of X-ray sources and through the work of many spectroscopists who were able to ascertain the binary nature of a number of objects which at Struve's time were very enigmatic. In regard to evolution, let me remind you that the idea that explains the Algol paradox was suggested by Crawford and Kraft and was readily accepted by Struve.

We have now advanced a great deal in our understanding of possible evolution in close binaries and Plavec is going in the right direction in trying to match theory with observations. So far the computations have taken for granted the mass exchange proposition and have felt somewhat satisfied in establishing the mass configuration and the position in the H – R diagram during evolution. The comparison with observations have made it clear that non-conservative cases should be taken up, as Plavec has shown, and this seems to be reasonable. Since the stage of rapid mass outflow from the more massive component of the system involves the loss of a substantial amount of mass in a relatively short time one would expect that there will be large velocities of outflow and, therefore, that mass will be lost to the system.

Much work has still to be done, both from the theoretical as well as from the observational side, until we understand the phase of rapid mass loss and, until we are able to describe each stage, the physics involved and can fully compare the result of the computations with the actual observed configuration. Then we will be able to

answer questions like when is the 'disk' or 'circumstellar envelope' formed, whether during the fast or the slow phase of evolution, and other similar questions.

Plavec has interpreted υ Sagittarii and the binaries X-ray sources as objects undergoing second mass exchange. Actually β Lyrae, V453 Scorpii and perhaps the whole group of stars that several years ago I classed together with β Lyrae, with perhaps the exception of HD 47129, are most probably undergoing second mass exchange.

Since I mention υ Sagittarii let me state that although everybody talks quite seriously of υ Sgr as being a helium-rich star, I feel that such a conclusion from a spectrum which has strong H emission and an outer envelope that displays lines of H and He I, is at least subject to doubt.

Since I am an observational astronomer I have stressed the type of observations that should be carried out at the present time, namely, simultaneous photometric and spectrographic investigations, quantitative spectrophotometric analysis and study of peculiar objects. What I have said also points towards our needs from the theoretical point of view. Commision 42 should perhaps discuss and agree at the next General Assembly on a number of objects that should preferentially be observed.

To put an end to these comments I would say that for me personally the Conference has been very valuable and inspiring indeed, and look forward to our next meeting where the results from the Parksville interaction between astronomers will be apparent.

Let me finish my words by saying that it was particularly interesting for me to find that my old friend Su-Shu Huang has developed such a skill to find good figurative comparisons to illustrate his descriptions and explanations. After his talk I have come to the conclusion that if I want to understand the dynamics of gaseous streams I should take up smoking!