INTRODUCTORY ADDRESS

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Abstract. The early history of the studies on Be stars is reviewed. The importance of keeping in mind a basic model of a Be star is emphasized, and the binary star model is suggested as one serious possibility at least for some Be stars.

The name *Be Star* was introduced by Commission 29 of the International Astronomical Union in 1922 at the first General Assembly of the Union in Rome. Walter S. Adams was President of the Commission at that time, but it was Henry N. Russell who actually presided over the meeting. Besides these two, the Commission had seven more members.

The Be stars were of course known before they were given the name. A good many of them were recognized when the HD catalog was compiled, and they were usually classified as Bp. In fact, the first two stars with emission lines were discovered by Angelo Secchi very soon after he began his systematic work on the first classification of stellar spectra. In 1866, Secchi noticed that Hβ was in emission in γ Cas and β Lyr. These two stars can therefore be considered as prototypes or symbols of sorts. At first, they were considered to be rather similar. Otto Struve probably more than anyone else separated them as different objects, while recently at least some of us have felt that there is more similarity than diversity between these two.

The first systematic observing program on emission line stars was, as far as I know, started by Ralph H. Curtiss in 1911 at Ann Arbor in Michigan. The very first publication (Curtiss, 1916) resulting from this project was devoted to γ Cassiopeae. I am sure many of you will be delighted to read Curtiss' argument why this star had been selected:

> It was hoped that the analysis of this simple spectrum would assist in the study of more complicated cases.

No doubt Curtiss soon learned the lesson that a spectrum with a few visible lines is not necessarily a simple spectrum. In fact, γ Cas has so far been the only Be star to display truly large changes in the integral light. I remember that when I first looked at the constellations in 1937 or 1938, Cassiopea was even more beautiful than now, having one star of the first magnitude.

In this context, however, it is good to recall the words of Curtiss' successor, McLaughlin (1932):

> Unusual developments may conceivably occur at any time in the spectrum of any one of them, furnishing us with an additional example of what a stellar atmosphere can do.

The series of Michigan publications on Be stars, published to 1929 by Curtiss and then by McLaughlin, is very interesting. In their *Surveys of the Brighter Be Stars*, one finds almost all the stars that still intrigue us today: γ Cas, β Lyr, ϕ Per, ψ Per, Pleione, ζ Tau, β Mon, even HR 2142 . . . .

A. Slettebak (ed.), Be and Shell Stars, 1–10. *All Rights Reserved*

Curtiss and McLaughlin soon recognized that many of the Be stars showed rather pronounced spectral variations, and that these variations often were cyclic or almost periodic. The concept of the E/C and V/R variations emerged from their papers, and McLaughlin spent a good deal of his life following these changes and attempting to explain them. In his enthusiasm and devotion to these stars, he had a good peer in Paul W. Merrill. The phrase "... what a stellar atmosphere can do" originally came from Paul Merrill (1929).

Paul Merrill became interested in stellar spectra, and in particular in the peculiar ones, when he participated in the large radial velocity program of the Lick Observatory. Before he started his own program in 1917–1919, however, he was able to acquire laboratory experience with the then new red-sensitive plates. While McLaughlin watched the emission lines, Merrill was much more attracted to the enigmatic spectra of the shell stars. The term *shell star* was apparently introduced by Otto Struve, but to him it was merely a convenient abbreviation for 'a star with an extended atmosphere'. Thanks mostly to the innumerable articles by Paul Merrill, the meaning of the term became narrower and more definite.

Paul Merrill covered dozens of pages of the Astrophysical Journal and of the Publications of the Astronomical Society of the Pacific with detailed descriptions of the various shell spectra, of their cycles and episodes. However, he was very reluctant to write a summarizing and interpretative article. His articles whose titles promise a review are extremely concise. Perhaps the most review-like article is the one entitled 'Stars with Expanding Envelopes', published in Volume II of Beer's *Vistas in Astronomy*. Even here, Merrill is extremely cautious and simply indicates that the phenomenon is very complex. His attitude is best expressed by the following sentence, to which McLaughlin alluded:

> The immediate outcome of this investigation is an example of what a stellar atmosphere can do. A complete interpretation of the observations in terms of physical conditions in the star will not be made at once – at least not by the author.

McLaughlin did attempt to interpret his observations in terms of a geometrical model. This model was a modification of the basic explanation of the Be star phenomenon made by Otto Struve in 1931. In that famous article, Struve made two essential observations: "Apparently, rapid rotation sponsors the occurrence of wide emission lines", and again "Rapid rotation seems to be prerequisite to the appearance of bright lines". As to the actual mechanism that leads to the eventual formation of the lines, Struve says:

> Sir James Jeans has shown that under certain conditions a rapidly rotating gaseous body may become lens-shaped and throw off matter at its sharp equatorial edge. It is therefore reasonable to expect that Be stars in extremely rapid rotation will eject gaseous matter at the equator. A gaseous ring will be formed and the system will resemble in appearance the planet Saturn. (Struve, 1931).

It was this rather too artificial jump from a rotationally unstable star to a detached circumstellar ring that enabled McLaughlin to suggest a qualitative explanation of the V/R variation. In his summarizing article on 'The Bright-Line Stars of Class B' (McLaughlin, 1961), he examines and rejects several possible models, and eventually (without too much enthusiasm), decides in favor of an elliptical ring. The model was recently revived by Su-Shu Huang (1973) and widely popularized in the June 1975 issue of *Sky and Telescope*.

It is rather easy to speak about the first generation of investigators, although even here we are committing a serious crime of distorting history if we speak only about the four leading astronomers. To summarize the more recent history of our subject is much more difficult. As in all branches of astrophysics, the quiet pleasant creek of scientific progress has turned, since World War II, into an impressive broad river, or at times into a wild torrent. It is better to talk about problems than about people.

I think in the field of Be and shell stars we have three specific problems that must be solved if we want to understand these objects: (1) line formation in an extended atmosphere; (2) relation between the rapid rotation of the central star and its Be character; (3) origin and dynamical support of the extended atmosphere. These problems are far from being solved; nevertheless, considerable progress has been made. Much of what has been done can be found summarized, reviewed, discussed and occasionally questioned and challenged in the proceedings of several recent meetings. Thus, the broad problem of stellar rotation and its influence on stellar spectra, stellar atmospheres, and stellar structure is thoroughly examined in the Proceedings of the IAU Colloquium No. 4, edited (quite appropriately) by Slettebak (1970) under the title *Stellar Rotation*. Another similar Colloquium, No. 2, was devoted to line formation in extended atmospheres, and its proceedings were published by Groth and Wellmann (1970). Although primarily devoted to the circumstellar matter in binary stars, the IAU Symposium No. 51 at Parksville had many contributions on the general problem of circumstellar envelopes. The proceedings, edited by Batten (1973), have the additional advantage of being published three years after the former two books, which means a lot considering the present rate of progress in astrophysics. Nevertheless, it was at Parksville that many of us agreed that another Symposium devoted specifically to Be stars and shell stars would be very valuable.

At times one feels that the Proceedings of various conferences, extremely valuable as they are, lack the unifying spirit and the personal flavor of a monograph. Fortunately, two good recent monographs deal rather extensively with our stars: Underhill (1966) covers them as an important group among *The Early Type Stars*, while Hack and Struve (1970) see them as one kind of the *Peculiar Stars*, which in the second volume of their *Stellar Spectroscopy* are given twice as much space as the *Normal Stars* in the first volume: a fact telling us something either about the nature of the stars, or about the human nature of the astronomers.

Naturally, no book can be written and published fast enough, and for the most recent accomplishments one must look into the current journals. Among the most recent and most outstanding achievements, I would like to mention: infrared photometry, and the discovery of an excess in the infrared radiation from many Be and related stars; the far ultraviolet observations from rockets and satellites, and the resulting discovery of stellar wind in luminous early-type stars; a vast progress in the treatment of the effects of rotation upon the spectral lines and stellar atmospheres; and a gradual but steady expansion into the field of extended atmospheres of the sophisticated methods developed originally for more normal atmospheres. If we add to these the substantial improvement in all kinds of spectroscopic, photometric, and polarimetric observations, as well as a similar progress in all aspects of theoretical astrophysics, we can be sure that new and fundamental discoveries in our field are coming.

I wonder how well I managed to conceal my effort to evade my assigned task to summarize the more recent history of our field. I claim that it cannot be done in a short talk, and, more important, that it is not necessary. This history is still alive, we live in it. The leading investigators are either personally present, or represented by their close collaborators or pupils. We will hear from them.

Thus I think I can abandon the historical approach here. Instead, I would like to invoke the brilliant introductory talk to the Magnetic Star Symposium delivered by Dr Bidelman ten years ago. I hope he will permit me to quote from his address (Bidelman, 1967):

> After all, in some ways, an introduction is a little bit like an overture to an opera. For instance, the overture isn't expected to be taken very seriously, because people are just supposed to be sliding – mentally or physically – into their seats. Furthermore, all the overture does is to give you bits and snatches of the tunes that are to be played, with ample elaboration, later on during the opera.
>
> At first I felt that this meant that I really shouldn't say very much. Then it occurred to me, following the analogy a bit further, that it often happens that the overture is the only part of the opera that survives.

I hope Dr Bidelman will permit me to exploit his allegory. His Introduction then was really a masterpiece which can be studied independently and with great profit. I will not attempt to do the same. There are operas where the orchestra plays just a few bars of introduction, the curtain goes up, and that's all for the overture. Nevertheless, if done properly, these few bars of introduction can bring us just to the middle of action and excitement on the stage. The problem is, how to create the proper atmosphere. I know a playwright who toys with the idea of opening his next play by firing two cannon shots from the stage into the audience. He claims that this is the

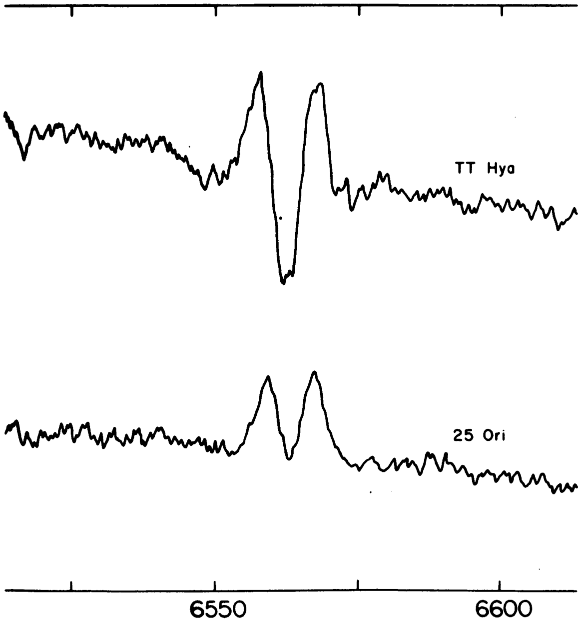

Fig. 1. Density tracings of similarly exposed spectrograms near Hα. The wavelength scale is in Ångströms. Original scale was 17 Å mm^{-1}.

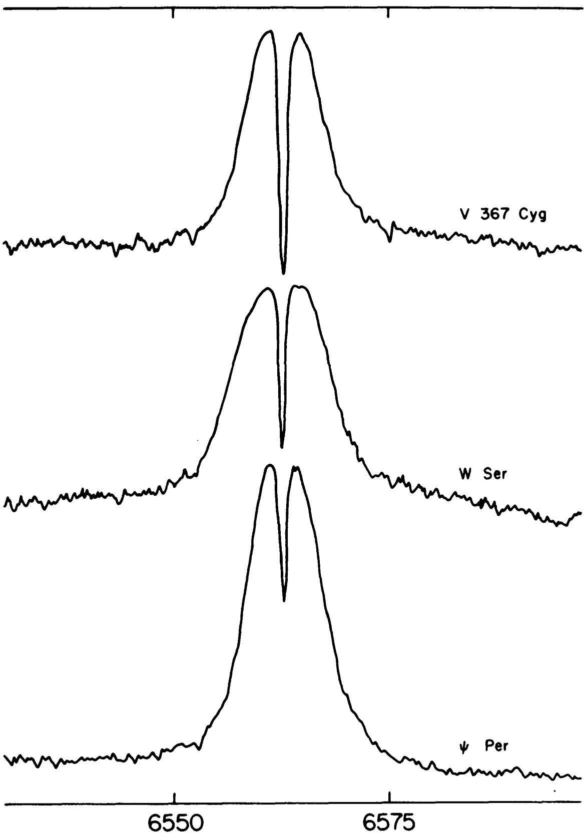

Fig. 2. Density tracings as in Figure 1.

only sure way to make everybody forget his daily problems and concentrate on what is happening on the stage. We do not have the necessary requisites here, so I will show you a few slides instead.

The pictures show the profiles of the Hα line obtained with the Varo image tube of the Lick Observatory by Peters, Polidan, and myself. In Figure 1, you have a classical Be star, 25 Ori, and an eclipsing binary, TT Hydrae. In Figure 2, we compare a rather typical shell star, ψ Persei, with two eclipsing binaries, V 367 Cygni and W Serpentis. Figure 3 shows another shell star, 88 Herculis, and the eclipsing binary RZ Scuti. Figure 4 shows a Be star η Cen sandwiched between two eclipsing stars, RX Gem and AU Mon. And, finally, Figure 5 shows the Be stars κ CMa and HR 3034 and the spectroscopic binary HD 698. This last figure shows two Be stars with single, narrow emission lines; and we can see that a similar case can be found among close binaries, too, but naturally we have to search among spectroscopic binaries, not among eclipsing binaries.

The five figures are meant to convey to you the extreme similarity between certain Be stars, shell stars, and close binaries. Now we understand in principle the mechanism by which the circumstellar emission or absorption lines are formed in

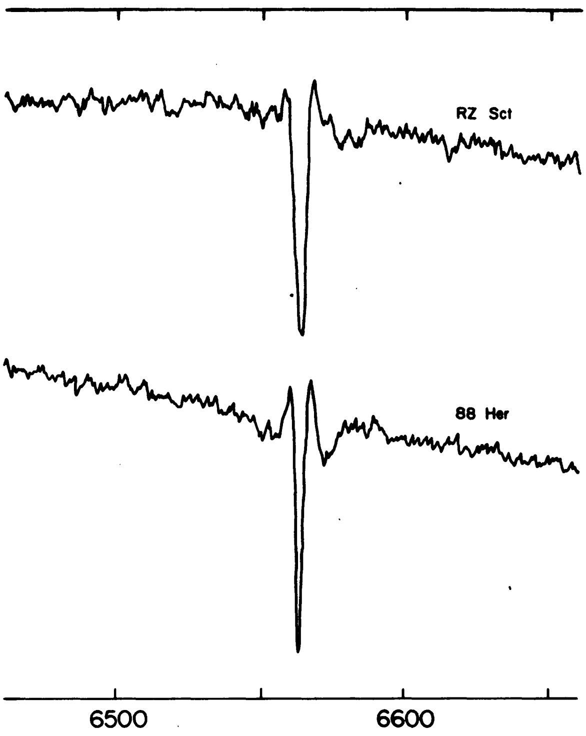

Fig. 3. Density tracings as in Figure 1.

close binaries. The cooler star in such a system is unstable and transfers mass to the hotter and brighter component. The streaming gas carries an excess angular momentum, and therefore forms a disk or ring around the other star. It is in this disk that most of the circumstellar emission or absorption lines originate. There is no problem in this case with the mechanical support for such a disk. The star inside the disk accretes only a fraction of the surrounding gas; however, if the star is relatively large, the impact is quite oblique and accelerates the rotation of the surface layers of the accreting star. Thus we get something similar to the Be star. Here, however, the envelope is not the result of an instability of a rapidly rotating star, as in Struve's picture; rather, the rapid rotation of the star's photospheric layers is a byproduct of the formation of the envelope.

We can go even farther and explain more by the binary model. The eclipsing binary star TT Hydrae displays an apparently periodic V/R variation during one orbital period of 7 days. We believe that this variation can be explained in terms of an uneven distribution of the circumstellar gas, and by the periodically changing geometrical aspect of the system. Much work remains to be done to convert this crude qualitative picture into a quantitative model. Nevertheless, I think that the binary model may very well explain many observed Be stars and shell stars.

It is really the central problem of all our investigations to understand how the extended circumstellar envelope we observe in the Be stars has been formed and how

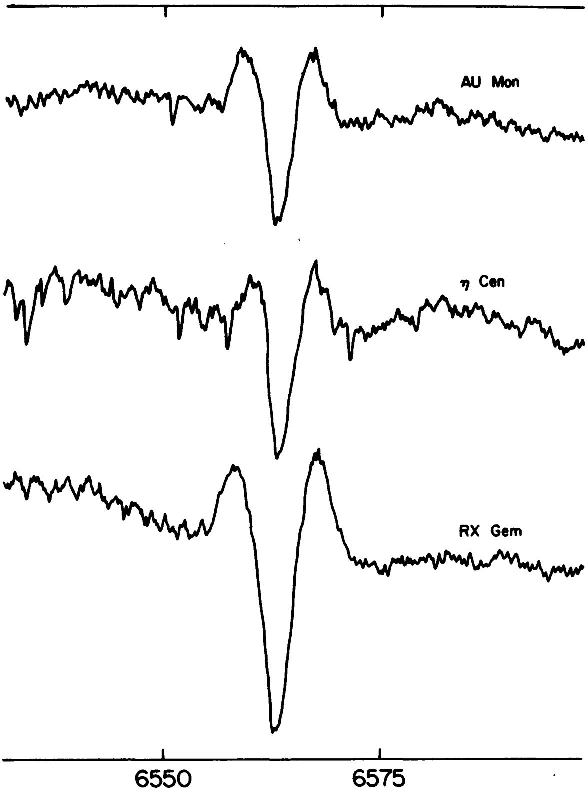

Fig. 4. Density tracings as in Figure 1.

it is maintained and supported. It is rather surprising that sometimes very vague concepts are accepted as a satisfactory explanation. This makes even more commendable the systematic efforts by Limber and Marlborough (1968) to clarify the question. They have developed the canonical picture proposed by Struve of a rotationally unstable star, but they emphasize that an additional force must be postulated. This model is often – rather crudely – presented in a form similar to Figure 6: a rapidly rotating star (which should therefore be flattened!) is surrounded, in the equatorial plane, by a flat disk. Some of you may prefer Huang's model of an elliptical ring, as shown schematically in Figure 7. This model is designed to explain the observed *V*/*R* variation. The origin of the ring is thought to be basically the same as in Struve's model. To me, it is rather difficult to imagine how such a ring could be formed and maintained. Vague doubts of course cannot eliminate these models, they can only stimulate further search for alternatives. The model of an interacting binary, shown schematically in Figure 8, is in my mind such an alternative. This model will be presented in more detail later on by Drs Harmanec, Polidan, Peters, and myself; however, our time will not come until the very end of the Symposium, which is the time to be tired and sleepy. This is why I am trying to call attention to it right now in the Introduction. If all the alternatives of the basic picture of a Be star are kept in

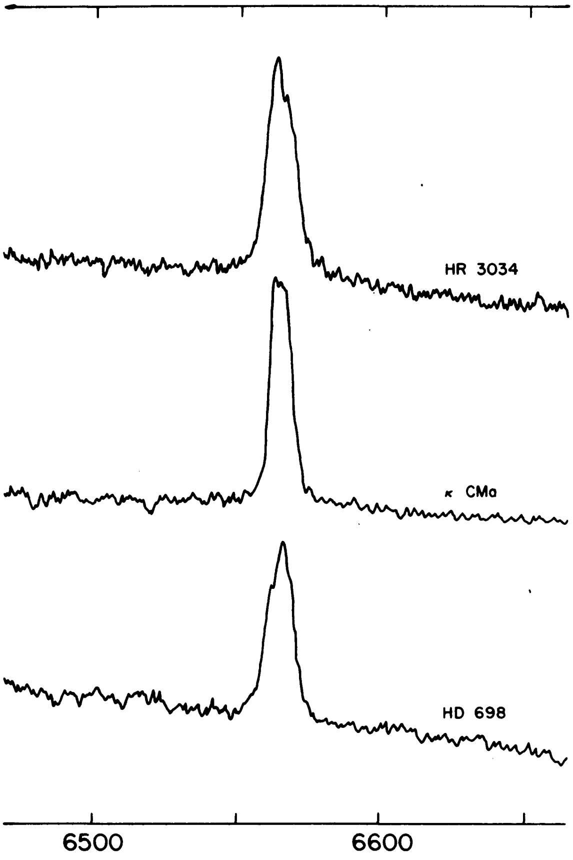

Fig. 5. Density tracings as in Figure 1.

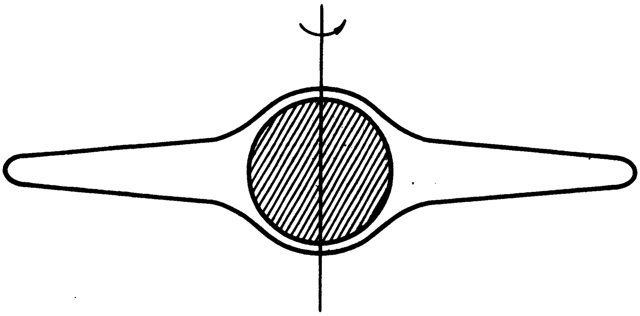

Fig. 6. The classical model of a Be star is usually given in this form, although the rapidly rotating star should be considerably flattened.

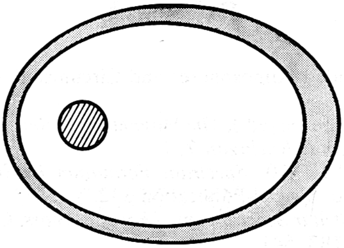

Fig. 7. This very schematic picture of an elliptical ring is often used to represent the Be star model proposed by McLaughlin and by Huang.

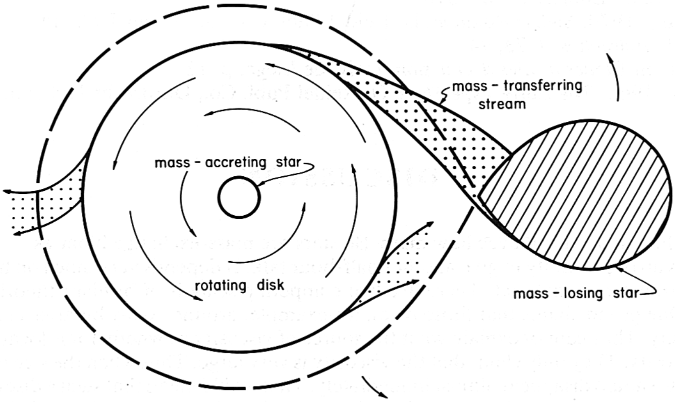

Fig. 8. Be star as an interacting binary: Gas streams from the large and cool giant into the disk surrounding the mass-accreting star. Additional weaker streams may be present as indicated.

mind during all the discussions, we will gather many stimulating thoughts and criticisms.

I heard Otto Struve narrate the story of his famous 1931 article on the Be stars: "The revolving-ring of gas hypothesis, in rapidly rotating stars, was written in the course of a rather long evening." (Struve, 1958). It is a fascinating story, quite fitting for the astronomical giant of the twentieth century, as Struve was recently called by Dr Huang. But it is also a challenging story. Many brilliant scientists are working on the problem of the Be stars nowadays; many combined evenings should in the end be a good match for that one in 1931. It would be very nice to say: "A very substantial progress in our understanding of the Be stars was accomplished in the course of a rather long Symposium." Perhaps that much cannot be achieved at any meeting; truly revolutionary ideas are more likely born in the solitude of long evenings. Nevertheless, this Symposium can certainly stimulate new thoughts and new projects. I hope it will.

Acknowledgements

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DISCUSSION

Schild: I would like to ask Dr Plavec how many Be stars are mass-exchange binaries.

Plavec: This is an opportunity to give another half-hour talk. It depends very much on how stable is the disc formed by transfer of material. There are two competing schools of brilliant theorists who cannot agree on that. One group claims that those discs, for example, around X-ray binaries are dominated by very large viscosity. They cannot explain what the source of viscosity is: whether it is local magnetic fields or turbulent viscosity. They only claim that the viscosity is very large. Thus when the stream of material is turned off the disc should disappear almost immediately. That would mean that such a disc could exist only as long as the other star supplies the material. In that case, the other star must be fairly large, and would have a fairly large probability of eclipses. And you can calculate that out of one hundred Be stars, fifteen should display eclipses, which has not been observed. In this case you would have to say that the binary hypothesis could account only for a certain fraction, not terribly large, of all the Be stars. We have direct evidence that it does explain some because we have observed the cool components, but it probably does not account for all of them. On the other hand, if the other school is correct, the disc has very low viscosity and the material is being transferred to the surface of the star by shock waves. In that case the ring will dissipate very slowly and when the mass transfer is finished the disc will stay there for a relatively long time. In that case it may happen that the disc is still there when the star has finished its mass transfer and the star is contracting and will become a helium star or a white dwarf star. In that case you cannot expect that there will be eclipses, because the star is already quite small. If this case is correct, it might be that the majority of the Be stars can be explained in terms of the binary star model. At least the objection of eclipses is not there.

Doazan: Are there many eclipsing binaries known which have lost their shell emission line characteristics?

Plavec: Probably. I think the phenomenon is variable, for example, in RW Tau and other stars. An unfortunate factor is that there has been no systematic observation of the emissions in eclipsing binaries. As in Be stars, the emission is mostly present at Hα and Hβ, and those lines are not too frequently observed. The observations are only occasional. Somebody studied the system, obtained the radial velocity curve, and forgot about the system for another 20 years. Therefore, our information is very scattered. Recently we discovered the sudden flaring up of emission in U Cep and it really does seem to be a variable phenomenon.