RELATED BINARIES, INCLUDING SYMBIOTIC STARS

Jorge Sahade
Instituto Argentino de Radioastronomía,
C.C. 5, 1894 Villa Elisa (Bs. As.), Argentina
Member of the Carrera del Investigador Científico,
CONICET, Argentina.

1. "RELATED" BINARIES

In the context of the Joint Discussion, it is clear that by "long period binaries" we understand the system of ε Aurigae and the ζ Aurigae systems. The question is, then, how to determine which systems could be considered "related" to those long period ones.

To help us find our way out, let us summarize first the main characteristics of ε Aur and the ζ Aur systems.

As we have been reminded in the preceding papers, ε Aur is a famous, single-lined eclipsing binary with an orbital period of 27 years. The spectrum which is observed at all phases, in the photographic region, is that of an FO Ia star with additional lines that are produced at different layers in its atmosphere, estimated by Struve (1956) to extend, at least, three times the stellar radius. The companion to the F supergiant has a radius much smaller than that of the latter star, and is never observed because it is surrounded by an opaque disk located in the equatorial plane of the star, as suggested by Huang (1965) about twenty years ago. The disk must thin out towards the edges, and the so-called "satellite" lines, that are observed before first contact and immediately after fourth contact, must result from the absorption of the radiation from the F supergiant by the outer regions of the disk, as it is also the case in β Lyrae (Batten and Sahade 1973).

There is no way of determining directly the individual masses of the component stars, but the value of the mass-function, namely, 3.12 $\mathfrak{M}_\odot$, as quoted by Sahade and Wood (1978) in their book, suggests that the mass of the unobservable companion to the F supergiant is, most probably, the larger of the two. And this seems to be an unescapable conclusion in the case of ε Aur because, if the thick accretion disk has the dimensions that are suggested by the observational data, then the mass of the hidden star must be equal or larger than that of the F supergiant.

J.-P. Swings (ed.), Highlights of Astronomy, 175–183.
© 1986 by the IAU.

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press

All we have said in regard to ε Aur seems to strongly suggest that we are dealing with an interacting binary in the first episode of mass loss, perhaps at the end of the rapid mass loss stage.

As for the ζ Aur systems, they are double-lined systems formed by a late type (G, K or M) supergiant, that is surrounded by a very extended atmosphere, and a B main sequence component, the radius of which is, of course, much smaller than that of the late supergiant. The orbital periods are, generally, of several years but there seems to exist cases where we deal with periods which are only a fraction of a year. In regard to the masses, the late supergiant is always more massive than the B main sequence star, except in the case of VV Cephei, where the masses of the two components seem to be about equal and too large for the spectral types concerned. Thus, in the Aur systems, the mass of the most evolved component is larger, and the mass of the companion is about what one would expect for their spectral type and luminosity class, as though there has been no important interaction between the components. Some interaction seems, however, to exist. From an analysis of IUE observations of ζ Aur, Chapman (1981) found that in this system there is indeed an interaction of the stellar wind from the K supergiant with the B component. We have no similar information in regard to other members of the group but the fact that all late supergiants are characterized by similar winds, makes it reasonable to generalize and to say that Chapman's picture for ζ Aur would very likely hold for all ζ Aur systems.

From what we have said, it would seem that the ζ Aur systems are in an evolutionary stage which we could call "pre-Algol". Do they ever become "Algol" systems, as far as the mass configuration is concerned? The very existence of Aur strongly suggests that the answer must be "yes" and we should perhaps, then, expect that ζ Aur stars might eventually become ε Aur-type systems.

If we accept all the above, we can now attempt to decide which binaries are "related" binaries. Since we consider that the ζ Aur systems are "pre-Algol" systems and ε Aur is an evolved system in the first episode of mass loss perhaps at the end of the rapid mass loss stage, it might be interesting to look for and to find systems that would seem to be related somehow to ε Aur.

If we go through the different groups that we can distinguish among close binary systems, we come across one which I called attention to at the 1963 NASA New York Symposium on Stellar Evolution (Sahade 1966a) and, the following year, at the IAU General Assembly in Hamburg (Sahade 1966b). In such a group I originally included the systems ε Aur, W Cru, HD 698, HD 47129, β Lyr, V453 Scorpii (HD 163181), V444 Cygni (HD 190967) and AO Cassiopeiae. In order to have an homogeneous group we should however, drop HD 47129 because this system seems to behave differently than the rest of the objects in the list, as far as the direction of the gaseous stream. We should also drop HD 698 because it is not an eclipsing system and, therefore, we cannot derive information regarding

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press

the structure and the kinematics of the gaseous material that exists in the system.

Table 1 lists the remaining systems which are characterized by the following facts:

Table 1
"Related" Binaries

Object	Orbital Period (Days)	Spectrum	$\mathfrak{M}$ Brighter	$f(\mathfrak{M})$	$\mathfrak{M}$ Fainter
ε Aur	9890	FO Ia		3.12	
W Cru	198.5	Gl I		5.82	
β Lyr	12.9	B8 II		8.37	
V453 Sco	12.0	BO.5 Ia	12.4		21.7
V448 Cyg	6.5	Bl Ib - II	16.6		21.3
AO Cas	3.5	09 III + 09 III	10.1		12.9

a) large mass-functions $[f(\mathfrak{M}) \gg 1]$;

b) the less massive and larger component is a supergiant or a giant, normally of early spectral type; the companion is more massive and smaller;

c) gaseous matter flows from the less massive, larger component towards the more massive, smaller component.

In our group, only ε Aur and β Lyr show evidence for a thick accretion disk around the smaller, more massive components. These accretion disks hide the components from view and in both we observe "satellite" lines in the spectrum, when the radiation from the primary component goes through the tenuous, outer layers of the disk. It is possible that W Cru may provide a third similar case, but this object is faint and the number of spectrograms availabe is not too large to tell exactly; it appears, however, very likely that W Cru may also be characterized by an accretion disk around the fainter component.

In the case of V453 Sco there is a thick envelope around the fainter component which gives rise to emission lines that follow the orbital motion of the star, in the same way as it seems to be true of the broad component of the H emission in β Lyr (Batten and Sahade 1973).

In V448 Cyg and in AO Cas there seems to be no accretion disk in the systems and the evidence is for masses of gas that move towards the advancing hemisphere of the smaller component.

It is possible and quite likely that, although the members of the group are in the same stage of evolution, not all of them are similarly

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press

advanced in such stage and this might explain the difference in the characteristics of the gaseous structure.

A candidate to join the group may be HD 187399, but we still need more information to ascertain this.

Another candidate would seem to be GG Carinae. GG Car is a 31-day-period binary where none of the components are observed in the photographic spectrum but only evidence is found for the existence of a thick envelope around one of the components and a thinner envelope around the system.

Let us say a word in regard to the behavior of our stars in the IUE ultraviolet. All our stars have been observed with the IUE satellite, but I have seen no results published for V448 Cyg neither for HD 698 nor for HD 187399. Should we assume that this is so because they do not display emissions? The first two stars were observed with low dispersion and the third one, in both modes.

The six stars of our group display high temperature resonance lines of the highly ionized species of N V, Si IV and C IV. In the spectrum of ε Aur they appear in absorption and are probably formed in the primary's transition region. Emission of OI at around 1300 A, that is present, must be formed in the outer layers of a probably very extended envelope that surrounds the whole system.

The rest of the objects display the high temperature lines as P Cygni profiles, on the high dispersion images, (β Lyr, V453 Sco, AO Cas) or simply as emission features on low dispersion material (W Cru). In GG Car the high temeperature resonance lines appear in absorption (Swings 1985).

In consequence, there is a different behavior in the gaseous material that gives rise to the high temperature resonance lines. A different mechanism may be producing the non-thermal radiation that shows its signature in the high temperature lines. As I just suggested, in ε Aur we are probably dealing with the normal transition region of the FO supergiant; in the rest of the objects where there is Roche lobe overflow, the normal structure of the stellar atmosphere of the object which fills its Roche lobe cannot be maintained and the high temperature resonance lines must arise from the dissipation of shock waves produced when the gas stream from the larger component encounters the thick envelope around the companion and/or when the gas leaving the system interacts with the outer envelope. In the case of β Lyr, the velocity derived from the violet absorptions practically coincides with the velocity from the diluted lines of He I in the photographic region. In consequence, it seems reasonable to conclude that the P Cygni profiles originate in matter that surrounds the system and is going away from its domain to enrich the interstellar space.

In the case of β Lyr, the object has been found to be a faint radio source and also a not too strong X radiator. The latter fact would

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press

indicate that the dissipation of shock waves at either of the two possibilities that I have mentioned, raises the temperature to values of the order of a million degrees. By the way, this seems to be true also in β Persei.

2. SYMBIOTIC STARS

In my discussion I am supposed to include the symbiotic stars. Recently David Allen (1984) published a new Catalogue of this type of objects which contains 129 entries. I have gone through the available data particularly in the IUE ultraviolet, for 18 of them - EG Andromedae, AX Persei, BX Monocerotis, RX Puppis, SY Muscae, RW Hydrae, T Coronae Borealis, AG Draconis, RS Ophiuchi, AR Pavonis, BF Cygni, CH Cygni, CI Cygni, V1016 Cygni, RR Telescopii, AG Pegasi, Z Andromedae and R Aquarii - and fir 4 additional objects that at one time or another have been considered as symbiotic or symbiotic-related stars, namely, 17 Leporis, WY Geminorum, AX Monocerotis, and WY Velorum.

The criterium for admitting an object in the symbiotic fraternity is provided by the original Merrill's definition of symbiotic stars which singles out the objects with spectra that combine low temperature features with emissions that require high excitation conditions.

The low temperature object is a late type giant, normally of spectral type M, but it could be as early as G. In the infrared, the symbiotic objects behave purely as the late type giants. Observing in this region of the spectrum, Webster and Allen (1975) found that the symbiotic stars can be classified into two groups, namely, the symbiotic stars with circumstellar dust emission, which they labeled D, and the symbiotic stars with no circumstellar dust emission, which they labeled S. Feast et al (1977, 1983a,1983b) and Whitelock et al (1983a,1983b) have shown that the late object in D-type systems are Mira variables.

The interpretation of symbiotic objects as binary systems was proposed as early as in 1932 and now it is a concept more or less generally agreed upon. Actually there exists a number of symbiotic objects for which the possibility of their binary nature does not appear to have received much support from the conventional type of observations. The IUE observations, however, and I believe this is true in all the cases that have been studied, show that the continuum corresponds to a higher temperature object than the late type component.In some cases, the continuum suggests that we are dealing with a star, that is, with only a star. In some other cases it seems that a star is not enough to account for the continuum and additional sources ought to be added, like the effect of a nebulosity (two photon emission) and/or that of an accretion disk around the hot component of the system. Moreover, non-thermal sources appear to exist in the systems, since in all those that have been observed in the satellite ultraviolet spectral regions, we find the presence in the spectrum of resonance lines of highly excited atoms that require very high temperatures for their formation. In the 18 objects common to our sample and to Allen's Catalogue, except for CH Cyg, the

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press

spectra are essentially emission spectra, particularly in the short wavelength region. In the long wavelength domain, the spectra are normally not too rich in emission, and sometimes they are devoid of them. But, of course, there are cases - SY Mus, RS Oph, RR Tel - where we find a large number of emissions also in the long wavelength range.

CH Cyg displays OI at around 1300 A and Mg II 2800 in emission, while the resonance lines of N V, Si IV and C IV appear in absorption, a behavior that reminds us somwhat that of ϵ Aur.

Boyarchuck (1969,1975) tried to explain the energy distribution in a few symbiotic objects and was led to postulate that they arise from three sources, namely, a giant star of type G-M, a small hot star with a $T_{eff} \simeq 10^5$ K, and a nebula with $T_e \simeq 17000$K and $n_e > 10^6$ cm^{-3}. Moreover, in the same papers Boyarchuck showed, for a number of symbiotic objects that, if the cool component is a normal giant, of luminosity class III, the hot companions fall below the main sequence, on the temperature-luminosity diagram.

Even though the temperature that Boyarchuck attributes to the hot star appears to be rather high, the now generally adopted picture for a symbiotic binary is that of a system formed by a red giant and a hot subdwarf plus a nebula associated to the system and excited by the hot component.

The periods of the known binaries are of the order of a few years, and the mass-functions are smaller than one. The late type giant should be the less massive component of the system and probably fills the critical Roche inner equipotential surface. It is argued that in some cases it is not so and although this may be true, it does not seem that at the moment, the observational evidence is enough to tell that for sure.

In regard to the secondary component, Allen (1984) states that "the absence of hard X-rays in all but V2116 Ophiuchi precludes a neutron star or a black hole as the accretor, and the debate therefore ranges around main sequence stars, subdwarfs or white dwarfs."

In a very few cases the observations do suggest that the secondaries are indeed subdwarfs and one would be tempted to generalize and conclude, as Sahade (1976) did suggest, that with the symbiotic objects we are dealing with systems undergoing a second episode of mass loss, at the beginning of it, according to Plavec (1982). It appears, however, possible to interpret some of the symbiotic objects as binaries with the secondary component being a main sequence star. If this could become an established fact, then we would have two groups of symbiotic objects, one representing binaries in an advanced stage of evolution, in a second episode of mass outflow. The other group would represent binaries with symbiotic spectra in a sort of "pre-Algol" stage of evolution. We would apparently also have single symbiotic stars. All this, at least, for the time being. It would be very important to try to as-

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press

certain whether this is the actual situation. My guess - as well as Allen's (1984) - is that symbiotic stars are all binaries; moreover, that they are in a second episode of mass loss and, therefore, that they represent a more advanced stage of evolution than the systems that we have discussed when dealing with the ζ Aur systems and with ε Aur.

If this were so, then 17 Lep would probably remain in the group and AX Mon would not. Regarding WY Vel, an [FeV] emission and other possible emissions have been identified in the IUE long wavelength range. If this is confirmed, we would have then no doubts that WY Vel belongs among the symbiolic objects. A similar thing happens with WY Gem.

It seems appropriate to make some comments in regard to the ultraviolet observations. Normally, the symbiotic objects in the sample, display a predominantly emission spectrum in the short wavelength range, that includes the resonance lines of N V, Si V and C IV. A few of the objects, however, are dominated by absorption features which also include the resonance lines of N V, Si IV and C IV.

The difference in behavior of the high temperature resonance lines N V, Si IV and C IV which appear in emission in a number of objects and in absorption in others deserves some thought. Perhaps we should keep in mind what happens in the Algol-type and similar systems, and, in the case of some symbiotic objects, what happens in ε Aur.

The relatively short-period Algols like RW Tauri and TT Hydrae -U Cephei not always- show the emission from the ring around the primaries, at Hα , only at principal eclipse when the light of the system drops by much more than one magnitude and the exposures are very much longer: there is not enough matter in the ring for the emission to appear when exposing the system in full light. Instead, in the systems of SX Cassiopeiae, RX Cassiopeiae and RZ Ophiuchi, the emission from the ring is observed in their spectra throughout the orbital cycles. The latter are longer period binaries and then the matter that could gather in the domain of the primary component could be large enough so as to produce a strong emission that appears on the plate together with the spectrum of the brighter star.

A similar thing happens with these systems and with similar systems, in the IUE ultraviolet. In RW Tau and TT Hya, as well as in U Cep and other similar systems, the resonance lines of N V, Si IV and C IV appear in emission, only at principal eclipse, while during the rest of the orbital cycle they appear in absorption. On the other hand, in SX Cas and RX Cas the resonance lines of N V, Si IV and C IV, as well as other lines appear in emission throughout the orbital cycle. So, it would seem that an explanation similar to the one devised for the photographic region must be also valid for the ultraviolet. This has been already noted by Plavec et al (1984). And in all these systems the high temperature lines would, then, form in the neighborhood of the primary component.

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press

For a few systems we have studied, (AU Monocerotis, γ_2 Velorum and β Per), we have, however, suggested that there are actually two regions of formation of high temperature lines, and further observations are going to be carried out, in a favorable case, namely that of β Per (cf. Sahade and Hernández 1985) to ascertain whether or not the suggestion is right.

In the case of β Lyr, the resonance lines of N V, Si IV and C IV display P Cygni profiles and the velocities from the violet absorption features coincide with the velocity that is suggested by the diluted line of He I 3888 A, as we have already mentioned. Therefore, the P Cygni profiles are formed in an outer, expanding envelope. Here again, some years ago it was also suggested (Hack *et al* 1976) that in the system of β Lyr there are two non-thermal high temperature regions, but this is not readily concluded from the IUE images and, at present, we are carrying a careful scrutiny to clarify the situation.

3. CONCLUSIONS

3.1 From the discussion we have presented, it would seem that there is a group of binaries that appear to be in a similar stage of evolution as ϵ Aur. The ζ Aur systems would be less evolved while, generally, the symbiotic binaries would be much more evolved objects.

3.2 From the behavior of binaries in the ultraviolet, it would not appear to be appropriate to try to sort out systems on account of the high temperature resonance lines -which are present in practically every binary system - being in absorption or in emission. A more useful distinction might be related to the location of the regions where the high temperature lines are formed.

I am indebted to Miss Marta Viviana Soler for carefully typing the manuscript.

REFERENCES

Allen, D.A. 1984, *Proc. Astron. Soc. Australia* **5**, 369.
Batten, A.H. and Sahade, J. 1973, *Pub. Astron. Soc. Pacific* **85**, 599.
Boyarchuck, A.A. 1969, in *Non-Periodic Phenomena in Variable Stars*, ed. L. Detre (Budapest: Academic Press), p . 395.
Boyarchuck, A.A. 1975, in *Variable Stars and Stellar Evolution*, eds. V.E. Sherwood and L. Plaut (Dordrecht: Reidel), p. 377.
Chapman, R.D. 1981, *Astrophys. J.* **248**,1043.
Feast, M.W., Catchpole, R.M., Whitelock, P.A., Carter, B.S. and Roberts, G. 1983a, *Mon. Not. R. astron. Soc.* **203**, 373.
Feast, M.W., Robertson, B.S.C. and Catchpole, R.M. 1977, *Mon. Not. R. astron. Soc.* **179**, 499.
Feast, M.W., Whitelock, P.A., Catchpole, R.M., Roberts, G. and Carter, B.S. 1983b, *Mon. Not. R. astron. Soc.* **202**, 951.
Hack, M. van den Heuvel, E.P.J., Hoekstra, R., de Jager, C. and Sahade

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press

J. 1976, *Astron. Astrophys.* **50**, 335.

Huang, S.-S. 1965, *Astrophys. J.* **141**, 976.

Plavec, M. 1982, in *The Nature of Symbiotic Stars*, eds. M. Friedjung and R. Viotti (Dordrecht: Reidel), p. 231.

Plavec, M., Dobias, J.J., Etzel, P.B. and Weiland, J.L. 1984, in *Future Of Ultraviolet Astronomy Based on Six Years of IUE Research*, eds. J.M. Mead, R.D. Chapman and Y Kondo, NASA- CP 2349, p. 420.

Sahade, J. 1966a, in *Stellar Evolution*, eds. R. F. Stein and A.G.W. Cameron (New York: Plenum Press), p. 449.

Sahade, J. 1966b, *Trans. International Astron. Union* **12B**, 494.

Sahade, J. 1976, Mém. Soc. R. Sci. Liege, 6eme serie, **9**,'303.

Sahade, J. Brandi, E. and Fontenla, J.M. 1984, *Astron. Astrophys. Suppl. Ser.* **56**, 17.

Sahade, J. and Hernández, C.A. 1985, *Rev. Mexicana Astron. Astrofís.* **10**, 257.

Sahade, J. and Wood, F.B. 1978, in *Interacting Binary Stars* (Pergamon Press), p. 152.

Struve, O. 1956, *Pub. Astron. Soc. Pacific* **68**,27.

Swings, J.P. 1985, private communication.

Webster, B.L. and Allen, D.A. 1975, *Mon. Not. R. astron. Soc.***171**, 171.

Whitelock, P.A., Catchpole, R.M., Feast, W., Roberts, G. and Carter, B.S. 1983a, *Mon. Not. R. astron. Soc.* **208**, 363.

Whitelock, P.A., Feast, M.W., Catchpole, R.M., Carter, B.S. and Roberts, G. 1983b, *Mon. Not. R. astron. Soc.* **203**, 351.

https://doi.org/10.1017/S1539299600006389 Published online by Cambridge University Press