SESSION IV

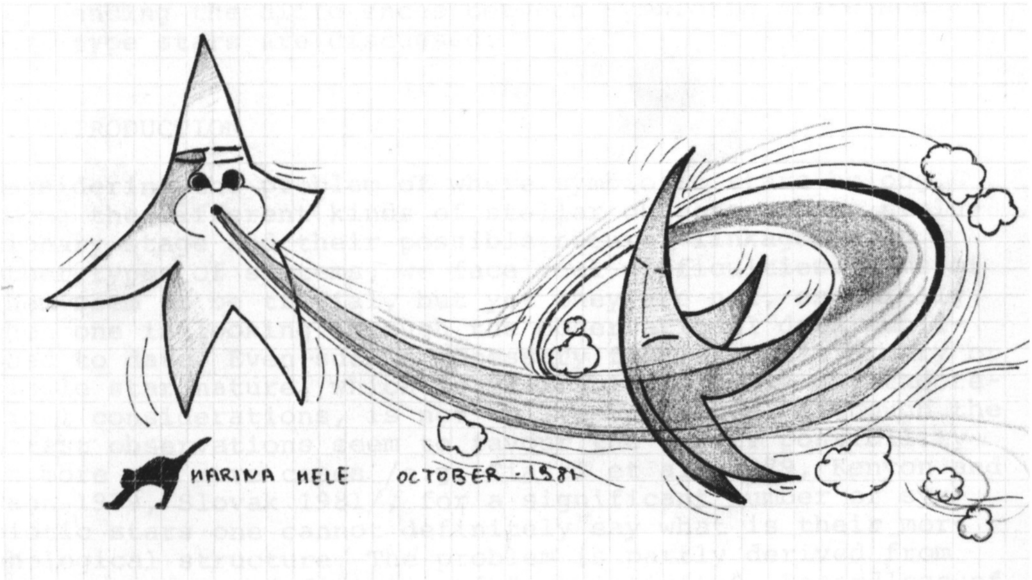
EVOLUTIONARY CONSIDERATIONS

Chairman: Y. Andrillat

Introductory reports on:

EVOLUTIONARY STATUS (B. Rudak)

MODEL OF SYMBIOTIC STARS (A.V. Tutukov and L.R. Yungelson)



Symbiotic Stars: Accretion onto a Companion?

THE EVOLUTIONARY STATUS OF SYMBIOTIC STARS

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Abstract: The evolutionary relations between symbiotic stars and cataclysmic variables are presented. The symbiotic stars are assumed to be long period detached binaries containing a carbon-oxygen degenerate primary and a red giant losing its mass through a spherically symmetric wind. Such systems can be obtained in Case C evolution, provided a common envelope during a rapid mass transfer phase was not formed. The same way recurrent novae containing a red giant as a secondary component may be produced. The factors influencing the differences between symbiotic stars and nova-type stars are discussed.

1. INTRODUCTION

Considering the problem of where symbiotic stars belong among the different kinds of stellar objects, their evolutionary stage and their possible natural linkages with other types of systems, we face real difficulties. Some of them seem to be trivial, but yet they are not, especially when one is looking through the observational data published to date. Even such a necessary fact as their binary or single star nature, which is desirable to begin any theoretical considerations, is not well established. Although the latest observations seem to favour the former possibility in more and more cases /e.g. Ciatti et al. 1979, Kenyon and Cahn 1979, Slovak 1981/, for a significant number of symbiotic stars one cannot definitely say what is their morphological structure. The problem is partly derived from the non-precise definition of "symbioticity". Regardless of three or four necessary conditions to be fulfiled, it is still a very general term, and as such, leaves room for some objects which have nothing to do with "classical" symbiotic stars. Thus the heterogeneity of the set of objects classified as symbiotic ought to be treated seriously.

M. Friedjung and R. Viotti (eds.), The Nature of Symbiotic Stars, 275–282.

In this review, however, we intend to focus our attention on those stars which are binary systems. We believe this group to be rather homogeneous, since one definite model can explain its behaviour, allowing for all particular observed differences between the member stars.
This resembles the situation of novae some fifteen years ago, when the wealth of observational data was at last satisfactorily explained.

2. GENERAL REMARKS

The idea of binary nature of Z And type stars was originally undertaken by Hogg in 1934, and then developed by Merrill, Payne-Gaposchkin, Struve, Swings, Kuiper and others. In the middle of seventies an interesting model was proposed by Bath /1977 and references therein/. Looking for tight couplings between symbiotic stars and cataclysmic binaries, Bath adopted his model of the latter group to explain the symbiotic phenomena. In that model, the binary consists of a main sequence dwarf or subdwarf and a red giant filling its Roche lobe. The activity of the system is due to instabilities arising in the outer layers of the giant, which in turn force the episodic mass transfer with a periodicity of few hundred days. The enhanced amount of matter falling onto the primary's surface at a super-Eddington rate via the accretion disk, causes a radiatively driven expansion of its photosphere.
Although such a model reproduces the general features of the behaviour of the above systems, there are observational indications which do not confirm Baths idea.

The binary nature of symbiotic stars was essentially deduced from variations in radial velocity curves, representing the movement of each component. The examination of these curves /Cowley and Stancel 1973, Boyarchuk 1975/ leads to the conclusion that the giant is the more massive component, with $\mathfrak{M} \approx 3 - 4 \mathfrak{M}_{\odot}$. In this case, the mass loss from the more massive star will cause a shrinkage of its Roche radius and a subsequent decrease of the orbital period. But after removing some material from the outer layer of the convective envelope, the new equilibrum radius cannot be fitted with a new smaller radius /Paczynski 1970/. This equilibrium radius is larger than the new Roche radius, so that a considerable amount of matter can be freely removed on a dynamical time scale for the giant. In effect, the majority of the giant's envelope will be quickly striped off revealing the degenerate core, and the mass ratio of the system will reverse. In other words, the life-time of symbiotic stars would be comparable to the dynamical time scale for giants.

That is why we doubt the model of red giants filling their Roche lobes in symbiotic binaries.

More careful examination of shapes of emission lines arising from the circumstellar matter, and observations of light changes on short time scales would show us if an accretion disks in symbiotic stars are really absent, as suggested by present-day observations. CI Cyg and CH Cyg seem to be the exceptions.

As for the main sequence component, one cannot rule out its presence, but new observations favour the primary to be a much more compact object /e.g. Allen 1980/.

Therefore through the rest of the paper we shall assume that, as in cataclysmic variable stars /Robinson 1976/, the hot components are white dwarfs.

So finally, we are left with a detached system containing a white dwarf and a red giant, as a compatible model for significant number of symbiotic stars.

3. THE PLACE OF SYMBIOTIC STARS AMONG EVOLVED BINARIES

The fate of an initially detached system of two main sequence stars depends mainly on their separation at that stage and the total mass of the system.

In principle, low-mass and massive binaries have to be described separately. For the latter group, usually the explosive carbon ignition inside the initially more massive component takes place at advanced stages of its evolution, giving rise to X-ray binaries with neutron stars or black holes. The critical mass which separates this group from the former one is not precisely established, but we can accept it to be near to $5 \mathfrak{M}_{\odot}$. Therefore, all symbiotic systems will fall safely into the low-mass group. As far as we know, there is only one object, GX 1+4, belonging to the massive group, which sometimes is classified as a possible member of the symbiotic stars. Nevertheless, the spectroscopy of this star was examined too poorly to treat this classification seriously. In any event its structure, with a probable neutron star component, does not fit the rest of the symbiotic stars.

From now on, when using the expression "binary system", we shall mean low-mass systems only.

Let us now repeat the most characteristic features of the different stages in binary evolution as a function of initial separation.

Consider first the system whose initial orbital period is larger than 1 day but shorter than 100 days. This will produce the so called Case B evolution. The initialy more massive component /primary/ attains its Roche lobe radius as a subgiant with a helium core and a hydrogen burning shell. The Roche lobe overflow causes rapid mass transfer through the inner Lagrangian point onto the secondary, a more or less evolved main sequence star. This effect proceeds on very short time scale compared to the stars life-time. For stars with radiative envelopes it is of the order of the thermal time scale, and for stars with developed convective envelopes it may be even shorter, approaching the dynamical time scale /Paczyński 1970/. This mass transfer forces a decrease in stellar separation, reaching its minimal value for $\mathfrak{M}_1 \approx \mathfrak{M}_2$, and then its subsequent increase. After the mass ratio is reversed, further mass loss goes on at a nuclear time scale for the hydrogen burning shell. This semi-detached phase lasts as long as there is a fresh hydrogen supply for burning in the shell. The resulting detached system, with a more massive secondary and a degenerate helium white dwarf primary will unavoidably form the semi-detached phase once again in its future: when the secondary manage to fill its Roche lobe, the mass transfer in the reversed direction will take place. If the mass ratio of the system is extreme enough before the primary overflows its Roche lobe, the rapid mass transfer can lead to the formation of dense common envelope around both stars. The drag, which will arise between this envelope and two orbiting stars embedded in it, is effective enough to transfer a considerable amount of angular momentum out of the binary system. This mechanism decreases the orbital period to the values well below 1 day. The binaries of Case B evolution, which underwent this stage, form as a result the class of cataclysmic variables.

Naturally, the mechanism which generates the activity of cataclysmic variables can work also for objects with periods already comparable to those of symbiotic stars /e.g. T CrB/. These exceptional objects managed to avoid the common envelope phase or were formed via Case C evolution, and the latter possibility explains naturally, why these stars are so similar to symbiotic objects. This point will be discussed later.

Because typical orbital periods for symbiotic binaries are longer than 100 days by a factor of 3 - 10, it is natural to seek their history in Case C evolution. This was independently considered by many authors /Paczyński 1980 and references therein/.

Case C evolution of a binary starts with separation wide enough to enable the ignition of the helium core before the primary reaches its Roche lobe. The initial mass of the primary in proto-symbiotic system is probably larger than $2\mathfrak{M}_\odot$, so that the helium ignition proceeds in the form of calm burning. As a result, a massive, degenerate carbon-oxygen core is formed. It is surrounded by an extended supergiant-type envelope expanding at the rate of nuclear burning in the hydrogen shell. After the star touches its Roche lobe, the rapid mass transfer onto the secondary can take place. As the existence of well developed burning shells enables the envelope to become deeply convective , the mass loss phase will last no longer than primary's dynamical time scale /for reasons already mentioned/. In effect, all hydrogen-rich matter of the envelope is rapidly transfered to the main sequence companion, leaving a degenerate C-O core which eventually can radiate at the expense of its own cooling only.

If the analogous to Case B common envelope is not formed during this mass transfer, the resulting orbital period will not be changed significantly, comparing to its initial value. The object is ready now to undergo the symbiotic phase of its evolution. The more massive secondary component developes now into a red giant, but still remains detached from its Roche lobe.

The spherically symmetric mass loss from its surface, enhanced by the vicinity of the Roche lobe can lead to a significant amount of accretion of this hydrogen-rich matter onto the white dwarf component. This will lead to the ignition of thermonuclear burning in the hydrogen and helium shells. Such explanation of activity of symbiotic stars was proposed by Tutukov and Yungelson /1976/, Paczyński and Żytkow /1978/ and Paczyński and Rudak /1980/. The advantage of such scenario lies in that, it naturally leads to the increase of primary's luminosity to the level at which it can compete with giant component's luminosity.

So, essentially the nature of symbiotic variability is identical to nova-type activity. Different are only the values of the characteristic parameters governing the quantitative picture of events. That is why the symbiotic stars of type II /in Paczyński and Rudak's notation/ resemble so much some of the recurrent and slow novae in their behaviour.

As main parameters we would mention here three of them, namely:

- accretion rate onto the primary $\dot{M}_{ac}$
- mass of the primary M_{core}
- CNO abundance of accreted matter.

Let us briefly consider the significance of each of these factors successively.

M_{ac} for classical and recurrent novae are relatively low and range from 10^{-9} to 10^{-7} $M_{\odot}$/yr, though the secondary component fills its Roche lobe. In effect, the hydrogen in the shell surrounding the degenerate core burns in the form of flashes only. A similar situation arises with type II symbiotic stars. But if $\dot{M}_{ac}$ exceeds the critical value $\dot{M}_{cr}$, stable burning takes place /Fig 1./. For details see Paczyński and Rudak /1980/.

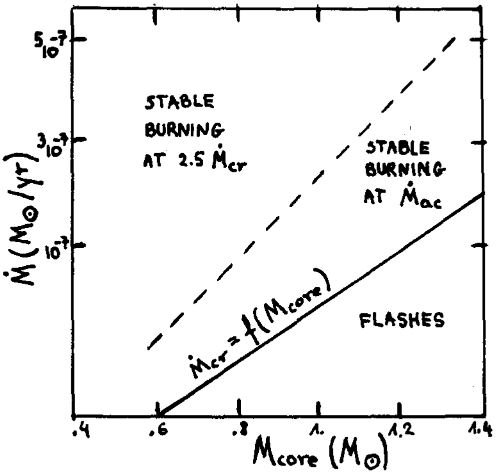

Fig 1. The ranges of hydrogen-burning character in shell for given core mass and accretion rate are shown. The falling matter has hydrogen content X=0.7, and shell burns on C-O core.

The second factor, M_{core}, plays a major role in determining the time scale of dynamical events on the surface of primary. This can be easily deduced from Fig 2., adopted from Paczyński /1971/. It represents the set of static envelopes built for different values of M_{core}.

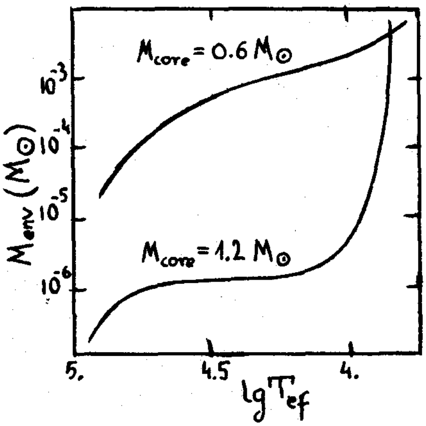

Fig 2. The dependance of static envelope mass surrounding the degenerate C-O core, on the effective temperature of the envelope /Paczyński 1971/.

We may see how sensitive the mass of envelope is to the value of M_{core}, and how sensitive the effective temperature of the primary is to any slight changes in M_{env} for the most massive cores.
The third factor governs the energetics of an outburst. It was shown by Starrfield et al. /1974/ that at temperatures exceeding 10^8K in the flashing shell, the rate of decay of β^+-unstable nuclei cannot be treated anymore to take place instantanously in the CNO cycle. Therefore the 10 - 100 folding enhancement of proton capturing nuclei in the burning matter is necessary to enable the explosive ejection of a massive envelope in fast-nova event. However, for slow nova outburst, the normal abundance is already sufficient to push out a considerable amount of the envelope by radiation pressure /Sparks et al. 1977, Prialnik et al. 1977/.
The outbursts observed for type II symbiotic stars resemble those of slow novae stars. This means that essentially, one would expect the normal CNO abundances in their ejecta.

The careful abundance analysis of both symbiotic stars and recurrent slow novae is necessary to find out if any differences in the CNO content can lead to the independent division between these two types of objects.

4. CONCLUSIONS

There is no doubt that symbiotic stars, whatever their character /single or binary stars/, represent advanced stages of stellar evolution.
Their distribution, though the sample is still not numerous, coincides with the old disk population /Boyarchuk 1975, Wallerstein 1980/.
The question, to what extent the symbiotic binaries constitute a common family with the cataclysmic binaries and double-core planetary nebulae cannot be answered before new observations are carried out. Though in few cases confusion arises in the proper classification of a given object as either symbiotic or e.g. recurrent nova, there is no doubt yet that the formation of binaries with initial orbital periods well over 100 days will favour their development to the symbiotic phase, provided the common envelope during the rapid mass transfer phase is not formed.
To understand the detailed processes which take place in symbiotic stars simultaneous observations in optical, UV and X-ray ranges during their activity are necessary.
The abundance analysis, particularly of CNO is also of great importance.
We should also expect positive results in looking for

possible content of s-process products. If the cool component is really a well evolved red giant with deep convection and effective mass loss, those elements will be abundant enough in the environment of symbiotic stars to be observed.

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