ON THE MODEL OF SYMBIOTIC STARS

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Abstract. We discuss conditions necessary for appearance and discovery of the symbiotic star phenomenon within the model of a binary consisting of a red (super)giant 3 $M_\odot$ not filling the Roche lobe and of an accreting hot degenerate CO-dwarf 0.8 $M_\odot$. Within this model "classical" symbiotic stars may exist only within a narrow region of mass accretion rates and separations of components: $10^{-7} \lesssim \dot{M} \lesssim 3 \cdot 10^{-7}$ $M_\odot$ /y and $3 \cdot 10^{13} \lesssim a \lesssim 2 \cdot 10^{14}$ cm. The evolutionary status of symbiotic stars and related objects and the mechanisms of their variability are discussed.

Introduction

Symbiotic stars are relatively rare irregular variable stars with spectra where molecular absorption bands are combined with high-excitation emission lines. The most complete review of their properties was given by Boyarchuk (1981). The best explanation of the features of symbiotic stars is provided by a model of a binary with one component a cold (super)giant (G-M), and the second - a hot star (Boyarchuk 1969, 1981). The binary nature of some symbiotic stars is directly indicated by variations of their radial velocities and light curves. The measured orbital periods of symbiotic stars are from $\sim$1 year to 26.7 years. Both components are immersed into an H II region with a radius of about 10^{15} - 10^{16} cm, $n_e \gtrsim 10^6 - 10^7$ cm^{-3}, T $\sim 10^4$ K. Wright and Allen (1978) who studied the radioemission of circumstellar matter found that the rate of mass inflow into the nebula is 10^{-6} - 10^{-5} $M_\odot$ /y. This is close to the outflow rates for Miras. The matter for the nebula is probably provided by stellar wind from cold star. It is possible that also a hot star ejects some matter into the nebula.

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Tutukov and Yungelson (1976) have shown that it is possible that hot components of symbiotic stars are degenerate carbon-oxygen dwarfs, the luminosity of which is provided by shell hydrogen burning of accreted stellar wind matter. The temperatures of carbon-oxygen dwarfs may reach values up to $\sim 10^6$ K (Pottash 1981). Temperatures of the same order are determined for the sources of excitation in some symbiotic stars (e.g. AG Dra, Oliversen et al. 1980). The ultraviolet emission of hot dwarf ionizes the matter of the nebula. A degenerate dwarf in a wide system is formed after the loss by the initially more massive component of its extended hydrogen-rich envelope.

Slovak and Africano (1978) have discovered that the symbiotic star CH Cyg is oscillating on the time-scale of about 5 minutes with an amplitude $0.^m02 - 0.^m04$. This indicates the presence of a compact energy source in this system. Allen (1980a) who studied line-widths in the spectra of some symbiotic stars has shown that for their hot components the value of $(M/M_\odot) / (R/R_\odot)$ is not less than 5, but for HM Sge it even exceeds 25. The data of Slovak and Africano and of Allen point also to the possibility of the presence of degenerate carbon-oxygen dwarfs in symbiotic stars.

There exists a number of objects with features close to those of "classical" symbiotic stars: stars with quite the same optical, IR and radio features, but without detected variations of visual magnitude. Those objects are sometimes called BQ[ ] -stars (Ciatti et al. 1974). Moreover, there are so-called slow novae, for which only one outburst was detected so far. Their spectra before the outbursts were similar to the spectra of symbiotic stars. There does not exist any unique classification of symbiotic and related stars. E.g. the same star AG Peg is named symbiotic (Boyarchuk 1970) and a slow nova (Allen 1980b) star. Both types of systems contain K or M (super)giants or Mira variables (Allen 1980b). It is possible that all objects with spectra in which features of a cold giant are combined with emission lines differ only in the frequency and amplitude of the outbursts.

Paczyński and Rudak (1980) suggested the classification of symbiotic stars based on differences in the kind of their activity and its sources. Symbiotic stars of type I have quasiperiodic variability in the time-scale of several months with amplitudes not greater than 4^m ; the high-excitation emission features are observed together with late giant features in the minima of brightness. The high excitation lines disappear when the brightness increases.

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On the basis of results of computations of hydrogen burning in the envelopes of accreting carbon-oxygen dwarfs Paczyński and Rudak have supposed that hydrogen burning in shell sources of hot components of type-I symbiotic stars is stationary, and that their optical variability is caused by variations of accretion rate which change the effective temperature of a dwarf almost without changing their luminosity. A typical representative of these stars is Z And.

In the spectra of type-II symbiotic stars low-excitation emission lines are observed, but the degree of excitation rapidly increases after the outbursts when the visual magnitude grows up to $\Delta m \approx 5^m$. During the outburst ejection of matter from a hot component is possible, and it may possess the stellar wind. The list of type-II symbiotic stars compiled by Paczyński and Rudak includes some stars named as slow novae by other students (e.g. V 1016 Cyg). Paczyński and Rudak have supposed that the activity of type-II stars is caused by nonstationary hydrogen burning in the envelopes of accreting dwarf components. Typical for type-II symbiotic stars is HM Sge.

The Model

The aim of the present paper is to study conditions necessary for the phenomenon of symbiotic stars. We shall study the model of a binary star that contains a red (super)giant accompanied by a hot carbon-oxygen dwarf. We take the mass of the dwarf equal to 0.8 $M_\odot$, that of the (super)giant - 3 $M_\odot$. These values of masses are quite typical because masses of carbon-oxygen dwarfs are 0.5 - 1.4 $M_\odot$, and the mass ratio in symbiotic stars is 3 to 4, while the lower limit of estimated masses of observed cold components is 3 $M_\odot$ (Boyarchuk 1970).

The cold component loses matter by stellar wind. Part α of this wind is captured by a dwarf:

$$\alpha \approx \frac{r^2}{4a^2} \approx \frac{G^2 m^2}{v^4 a^2} \approx \frac{m^2 R^2}{4M^2 a^2} \quad (1)$$

Here a is the distance between components, m - the dwarf mass, $r = 2Gm/v^2$ - the radius of capture by the white dwarf, $v = (2GM/R)^{1/2}$ - the velocity of stellar wind assumed to be equal to the escape one, M - the mass of the giant, R - its radius. The accretion onto the white dwarf supports the activity of the nuclear burning shell. The luminosity of the shell is limited by the Paczyński-Uus limit:

$L/L_\odot \lesssim 6 \cdot 10^4 \, (m/m_\odot - 0.5)$.

The system under study may be described by two parameters: the mass loss rate by the (super)giant $\dot{M}_G$ and the distance between components (Fig. 1). Employing (1)

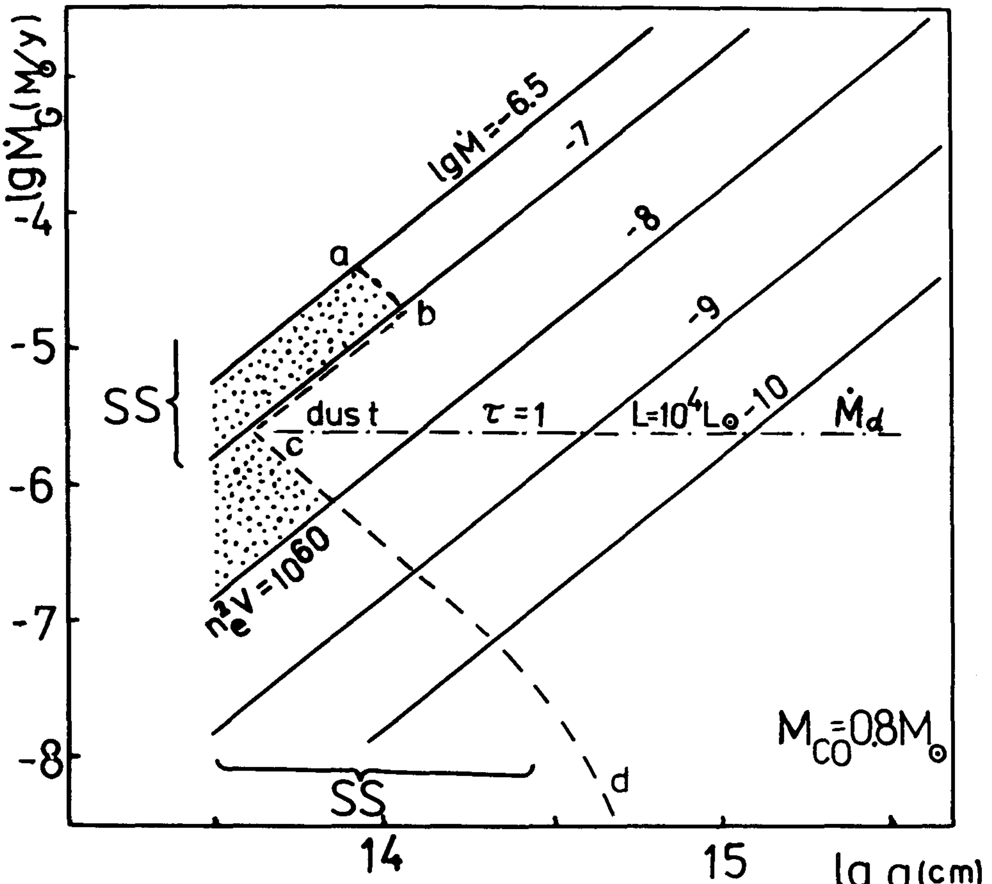

Figure 1. The relation between the separation of components and mass loss rate by giant 3 $M_\odot$ for wide binary systems. The lines of constant mass accretion rate by 0.8 $M_\odot$ carbon-oxygen degenerate dwarf are marked by values of lg $\dot{M}$ in $M_\odot$ /y. Lines a-b and c-d limit the region where the system is not screened by dust from the (super)-giant envelope. Type-I symbiotic stars exist in the dotted region where $\dot{M} \gtrsim 10^{-7}$ $M_\odot$ /y, in the region of lower $\dot{M}$ type-II symbiotic stars exist. The values of a and $\dot{M}_G$ observed in symbiotic stars are indicated. $\dot{M}_d$ is the mass loss rate for which the optical thickness of the dust in the envelope is 1 (for $L_G = 10^4\, L_\odot$).

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we may plot in Fig. 1 the lines of constant accretion rate $\dot{M} = -\alpha \dot{M}_G$. (We assume for definiteness that $R = 3\cdot10^{13}$ cm.) Paczyński and Zytkow (1978) have shown that hydrogen burning in the thin shell sources of accreting degenerate carbon-oxygen dwarf 0.8 $M_\odot$ is stationary if $10^{-7} \lesssim \dot{M} \lesssim 3\cdot10^{-7}$ $M_\odot$/y. There does not exist any systematic study of conditions of stationary burning for other values of m. However, Sienkiewicz (1980) has shown that the thin sources are thermally stable only for $\dot{M}$ close to maximal, i.e. $\sim 10^{-7}$ $M_\odot$/y for all dwarfs $0.6\ M_\odot \lesssim M < 1.4\ M_\odot$. If the accretion rate exceeds about $3\cdot10^{-7}$ $M_\odot$/y, the accreted matter does not have enough time to burn out, the dwarf's envelope expands, cools out, its emission stops to ionize the outflowing matter and the symbiotic star phenomenon disappears. If the accretion rate is lower than about 10^{-7} $M_\odot$/y, hydrogen burning is nonstationary. Hydrogen burns in outbursts. Between the outbursts the matter is accumulated in the envelope, on the base of which the temperature is not high enough for hydrogen burning. If $\dot{M} \approx 10^{-10} - 10^{-7}$ $M_\odot$/y, the interval between outbursts is $10^2 - 10^7$ years (Tutukov and Ergma 1980). During the outbursts the radius and luminosity increase for $(10 - 10^3)$ years, the effective temperature decreases, and if the white dwarf does not have stellar wind strong enough to prevent its transformation into a red giant, the symbiotic star phenomenon disappears. Thus, stationary hydrogen burning necessary in the Paczyński-Rudak type-I symbiotic star model is possible in an extremely narrow interval of $\dot{M}$. If the conditions of stationary burning are not fulfilled ($\dot{M} < 10^{-7}$ $M_\odot$/y), the energy liberation during accretion determines the luminosity of the dwarf.

High-excitation emission lines typical for spectra of symbiotic stars appear in the compact H II regions around them. For the existence of a stationary H II region the flux of ionizing quanta must be high enough for primary ionization of all incoming from the giant matter and for ionization of hydrogen after recombination. We may write down this condition as

$$\frac{\dot{M}_G}{m_H} + \int_{R_d}^{R_{HII}} \left(\frac{\dot{M}_G}{4\pi x^2 V m_H} \right)^2 \alpha(T)\, 4\pi x^2 dx \lesssim \frac{\dot{M}_G r^2}{4a^2} \frac{\varepsilon}{E} . \quad (2)$$

Here m_H is the mass of a hydrogen atom, $\alpha(T) = 2.2\cdot10^{-13}$ cm^3/s for $T = 10^4$ K - recombination coefficient of hydrogen, ε - energy liberated by the burning of 1 g of hydrogen or by accretion of 1 g of it, $E = 2.2\cdot10^{-11}$ erg - energy of L_α -quantum. The integration of (2) must be performed from the dust formation radius R_d in the stellar

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wind, because if the border of H II region were beyond R_d, dust would screen out the giant, as the dust incoming into the H II zone does not evaporate. Taking the dust formation temperature $T_d \approx 10^3$ K, we find $R_d \approx 10^{12.3} (L_G/L_\odot)^{1/2}$ cm. Substituting $v = 5.15 \cdot 10^7$ cm/sec for $M_G = 3\,M_\odot$, $R_G = 3 \cdot 10^{13}$ cm, and integrating (2) we obtain

$$\dot{M}_G \lesssim 10^{-22.4} R_d \left(\frac{10^{12.7} \varepsilon}{a^2} - 1 \right) M_\odot/y \qquad (3)$$

The value of ε is $10^{18.8}$ erg/g for nuclear energy generation, and $\varepsilon = 10^{17}$ erg/g for accretion. In Fig. 1 the curves a-b and c-d correspond to condition (3) (we assumed that $L_G = 10^4\,L_\odot$ for determination of R_d). According to Boyarchuk (1970) for the parts of nebulae that radiate in the continuum the relation $n_e^2 V \gtrsim 10^{60}$ cm^{-3} is valid (V is the volume). Taking into account that most of the ionizing quanta are spent on ionization of recombined atoms we may write down:

$$\alpha(T) \cdot 10^{60} \lesssim \dot{M} \frac{\varepsilon}{E} \qquad \text{or,} \quad \dot{M} \gtrsim \frac{10^{10.8}}{\varepsilon} \, . \qquad (4)$$

This means that if the dwarf radiation is due to stationary shell-hydrogen burning, the condition of the discovery of continuum radiation of nebula $n_e^2 V \gtrsim 10^{60}$ cm^{-3} is always fulfilled. However, it is not fulfilled if the luminosity of the dwarf is due to accretion. In this case we may take the discovery of hydrogen recombination lines, e.g. the H_β -line, on the continuous background as the condition for discovery of a symbiotic star. If we require that the same amount of energy per 1 Å must be emitted by nebula in the H_β -line of width $\Delta\lambda$ as emitted by the cold component in the same spectrum region, we obtain:

$$L_{H_\beta} \approx \alpha_{42} n_e^2 V \frac{1.97 \cdot 10^{-8}}{\lambda \Delta\lambda} \gtrsim L_{mon} \, .$$

Substituting $\alpha_{42}(10^4 \text{K}, 10^6 \text{ cm}^{-3}) \approx 3.1 \cdot 10^{-14}$ cm^6/sec (Brocklehurst 1971), $L_{mon} = 2.2 \cdot 10^{31}$ erg/sec/Å, $\lambda = 4861$ Å we obtain

$$n_e^2 V \gtrsim 1.8 \cdot 10^{56} \Delta\lambda \text{ cm}^{-3} \, .$$

As for stars under consideration $\Delta\lambda$ is of the order of several tens of Å, we may take $n_e^2 V \gtrsim 10^{58}$ cm^{-3}. Then the nebula is detectable if $\dot{M} \gtrsim 10^{-8} M_\odot$/y.

One more limitation on the emergence of the symbiotic star phenomenon is due to the formation of dust in the matter outflowing from the (super)giant. If the H II region is not developed enough and does not stretch out up to the dust formation radius R_d, then the star will be observed as a symbiotic star only if the optical thickness of the dust is lower than 1. Taking $\varkappa_d \approx 10^2$ cm^2/g we may estimate that the dust does not screen the star if

$$\dot{M}_G \gtrsim \dot{M}_d \approx 10^{-7.6} (L_G/L_\odot)^{1/2}. \tag{5}$$

Discussion

Using expressions (3)-(5) we may distinguish the region of symbiotic stars in the $\dot{M}_G$-a diagram (Fig. 1). From the side of small a it is limited by the line a = R_G. Symbiotic stars with stationary shell sources of hydrogen burning the variability of which is due to the variability of accretion rate may exist in the region limited by the lines $\dot{M} \approx 10^{-7} M_\odot$/y and $\dot{M} \approx 3 \cdot 10^{-7} M_\odot$/y, and by the line a-b corresponding to the condition of the stationarity of the H II region without dust. If a and $\dot{M}_G$ are greater than those corresponding to the line a-b, the star is screened out by dust and becomes an infrared object which is possibly variable.

In the region $\dot{M} \lesssim 10^{-7} M_\odot$/y the existence is possible of objects with hot components, the luminosity of which is fed by liberation of energy at accretion. Dwarf components of these stars must be cooler, and the sizes of the emitting regions of their nebulae smaller than in symbiotic stars with stationary hydrogen burning. If in such binaries $\dot{M}_G$ and a exceed the values corresponding to the line c-d, but $\dot{M}_G \lesssim 10^{-6} - 10^{-5.5} M_\odot$/y, they will possess considerable infrared excesses. In those stars hydrogen burns out in outbursts separated by $10^2 - 10^7$ years. During the outbursts the luminosity of a star increases by several orders of magnitude, remains quite constant for several tens - several thousands of years (if the dwarf does not lose mass) and afterwards decreases to the initial state (Paczyński and Zytkow 1978). In "low" state one may probably identify these objects with BQ[ ]-stars, in "high" state - with symbiotic stars of type II or with slow novae. If $\dot{M}_G \gtrsim 10^{-5.5} M_\odot$/y, the dust completely reprocesses the optical radiation of stars into the infrared one, transforming them into infrared sources. The position of the region of symbiotic stars depends on the masses of components (see (1)).

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Observed symbiotic stars have the separations of components $a \lesssim 2 \cdot 10^{14}$ cm ($P \lesssim 10^4$ days), and mass loss rates $\dot{M}_G \gtrsim 10^{-6}\ M_\odot$/y (Wright and Allen 1978). These values of a and $\dot{M}_G$ cover the interval of parameters for which the excitation emission spectra of symbiotic stars may be explained by stationary shell hydrogen burning. Note that for given masses of components the interval of a is very narrow - only about 0.5 in lg a (see Fig. 1).

The energy generation by nuclear burning or by accretion can explain the source of emission spectrum excitation, but the source of observed variability still remains unclear. Accretion occurs through the disk. It is possible that the matter firstly accumulates in the ring and afterwards is accreted through the disk. Such a model was suggested by Osaki (1974) for explanation of large outbursts of U Gem stars that occur with the quasiperiod from tens to hundreds of days and have amplitudes up to $4^m - 5^m$. The accumulation of matter in the disk may be modulated by variations in the mass outflow rate from the cold component. The mass outflow rate may be modulated by e.g. filling now and again the Roche lobe by the variable cold component (CH Cyg, see Luud 1980) or by the instability of a Roche-lobe-filling star with a deep convective envelope (Bath 1978). The disk may also be unstable and/or have a nonhomogeneous structure. Probably the observed diverse variability of symbiotic stars may be explained by overlapping of several mechanisms.

In Fig. 1 the evolutionary track of a binary system passes from below to the top. The main parameter that determines the evolution is the mass loss rate by the cold component. As $\dot{M}_G$ grows the system may successively pass through the stage of BQ[ ] -star, which after the outburst may be identified with type-II symbiotic stars or slow novae, and afterwards - through the stage of a type-I symbiotic star. In systems which are wider than $(1.5 - 2) \cdot 10^{14}$ cm the symbiotic star phenomenon probably is not observed because at $\dot{M}_G \gtrsim 10^{-6}\ M_\odot$/y they are completely screened by dust and transform into infrared sources.

If a (super)giant has a companion, it may lead to the concentration of outflowing matter in the orbital plane of the system, and formation of an optically and geometrically thick gaseous disk. The outflow of matter from the (super)-giant ceases when the mass of its hydrogen envelope decreases to $\sim 10^{-3}\ M_\odot$ and the envelope begins to contract. In this stage, if the disk-like envelope of the system becomes transparent in polar directions, then due to radiation scattering of the central star one will observe a bipolar nebula, like Roberts-22, V 645 Cyg, CRL 618, IV Zw 67, M1-92 (Allen et al. 1980). In these nebulae the central star is an O-F supergiant. In some (10^3 - 10^4) years the supergiant will transform into a carbon-oxygen dwarf - a usual nucleus of planetary nebula which is also able to lose matter. When the radius of the expanding lost envelope reaches $\sim 3 \cdot 10^{17}$ cm, it will be ionized by the nucleus radiation and become a usual planetary nebula. Ciatti et al. (1978) have noted the similarity between the nebulae around HM Sge and V 1016 Cyg, which are classified as type-II symbiotic stars and slow novae, and the most compact planetary nebulae. The bipolar structure may be a peculiar feature of the planetary nebulae with binary cores. According to Seaton (1968) a considerable part of planetary nebulae has a bipolar structure. It is an extremely hard task to discover the binary nature of a planetary nebula that was formed from BQ[ ] or a symbiotic star due to the long orbital period of the system and to large difference in the luminosities of components, because the "old" dwarf without accretion rapidly cools.

Let us estimate the number of symbiotic stars in the Galaxy. The mass function of binary stars is

$$\frac{d^2 N}{d\lg a \; d\lg(M/M_\odot)} = \frac{1}{6}\left(\frac{M}{M_\odot}\right)^{-2.5}$$

According to Kraitcheva et al. (1978) the number of double stars per unity of lg a is constant for $10^{11} \lesssim a \lesssim 10^{17}$ cm. The lifetime of the red (super)giant is $\tau \approx M_G/\dot{M}_G \approx 10^5$ years for typical $\dot{M}_G \approx 10^{-5}$ $M_\odot$/y (see Fig.1). The mass interval of cold components is 3 to 10 $M_\odot$ (Boyarchuk 1970). Taking all these data we obtain:

$$N_{SS} \approx \frac{1}{12}\int_3^{10} \frac{10^5}{\left(\frac{M}{M_\odot}\right)^{2.5}} \, d\left(\frac{M}{M_\odot}\right) \approx 10^3 \; .$$

This number satisfactorily agrees with the estimate of the number of symbiotic stars in the Galaxy by Boyarchuk (1970) $\sim 10^3$, which is based on the counts of these stars in the vicinity of the Sun. We may increase our estimate if the symbiotic star phenomenon may also appear in systems with masses of components lower than 3 $M_\odot$, because the carbon-oxygen white dwarf may form in all binaries that are wide enough. The reason for the absence of stars with $M_G < 3$ $M_\odot$ among symbiotic stars with

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estimated giant component mass is still obscure. One of possible explanations is short duration of the mass loss stage with $\dot{M}_G \gtrsim 10^{-6}\ M_\odot/y$ by stars with $M_G \sim M_\odot$, and their lower mean luminosity. Besides, usual estimation of masses M_G according to their spectral type makes them unreliable.

According to Sienkiewicz (1980) the maximal effective temperature of carbon-oxygen dwarfs with hydrogen burning in the envelopes strongly depends on their mass. One may approximate this dependence by $\lg Te \approx 4.7 + M/M_\odot$ and use it for the estimation of the lower limit of the mass of the components of symbiotic stars. Our analysis is relevant if the system contains a carbon-oxygen dwarf. In principle the existence of systems where a cold supergiant is accompanied by a helium dwarf or a neutron star or a black hole is possible. A degenerate helium dwarf may form in a binary system from a star with a mass lower than 2.5 - 3 $M_\odot$ due to mass exchange. Hydrogen burning in the shell source of an accreting helium dwarf is unstable, the time-scale of instability is not less than $\sim 10^2$ years (Sienkiewicz 1980). Between the outbursts the luminosity of the dwarf may be supplied by accretion with $\varepsilon \sim 10^{17}$ erg/g and by cooling. Such a system may also be observed as a star with emission lines in the spectra. It is also possible for a carbon-oxygen dwarf in the symbiotic star to be accompanied by a giant with a helium core, if the mass loss rate by a giant exceeds $10^{-8} - 10^{-7}\ M_\odot/y$.

If the companion of a (super)giant is a neutron star or a black hole, then the supercritical accretion ($\dot{M} \gtrsim 10^{-8}\ M_\odot/y$) may lead to formation of an optically thick envelope around the compact object, in which the X-ray emission may be reprocessed into ultraviolet or optical emission. X-ray and ultraviolet emission may ionize the stellar wind matter. The degree of ionization and the temperature may be extremely high. It is possible that GX 1+4 is an example of such systems. It is a hard X-ray source in the optical spectrum of which high-excitation emission lines are discovered (Davidsen et al. 1977). In the case of supercritical accretion the formation of jets in polar directions, like those observed in SS 433, is possible.

Tutukov and Yungelson (1976) have mentioned that accretion onto a carbon-oxygen dwarf in a symbiotic star may increase its mass to the Chandrasekhar limit and change the thermal conditions of its interiors in such a way that at the instance when the mass of the dwarf reaches 1.39 $M_\odot$, its central density exceeds that in the 1.39 $M_\odot$ carbon-oxygen core of a single star. If $\rho_c \gtrsim 5 \cdot 10^9$ g/cm^3, the formation of a neutron star is possible after the Supernova explosion which is due to explosive carbon ignition.

To sum up, we may conclude that conditions necessary for phenomenon of a "classical" symbiotic star are fulfilled in a rather narrow interval of mass loss rates by cold components and of distances between components. The "region of existence" of symbiotic stars is limited by conditions for discovery of the emitting region and by conditions of the system screening by the dust. Outside this region, if mass loss rates by giant components are $\dot{M}_G \approx 10^{-7} - 10^{-6}$ $M_\odot$/y and a $\lesssim 10^{14}$ cm, the existence of stars with emission lines in spectra whose activity, however, differs from that of symbiotic stars is possible.

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DISCUSSION ON EVOLUTION

Kwok: It is interesting to note that a radiative-driven wind from the C,O core not only explains some of the nova characteristics, but it also prevents the C,O core to evolve backwards to become a red giant.

Rudak: That is true. Such a wind will tend to decrease the value of $\dot{M}_{acc}$. On the other hand, however, one would hardly expect the spheric ally symmetric accretion rate for these wide systems to be significantly larger than a maximal possible H-burning rate in the shell on a C-O core. For example, for the C-O core of 1 $M_{\odot}$, the accretion rate has to exceed $3x10^{-7}$ $M_{\odot}yr^{-1}$. Only in these pathological cases, the hot star would look like a giant or a supergiant, wuth its colour depending on the specific enthropy of accreted matter.

Cassatella: Is it expected from theory that during the thermonuclear burning on the surface of the hot primary, enough neutrons (rapid or slow) are liberated so that r or s-process elements are formed? Actually, Audouze et al. (1981 Astr. Ap. 93, 1) do observe s-process ele ments to be overabundant in the symbiotic star CI Cyg.
More in general, is it expected to see anomalies in the chemical abundan ces in symbiotic stars like is observed for example in classical novae?

Rudak: The reason for which the enhanced abundances of s-process elements are observed in some symbiotic objects lies not necessarily in the presence of a degenerate hot component burning shells on its surface. Well developed convection in the red giant component evolves both the origin of a slab with H, C and O, where slow neutrons are produced, and the effective transport of s-process elements onto the giant's surface.

Plavec: There seems to be a difference in vocabulary between the theorists and the observers, which may lead to misunderstandings and pos sible gaps - - apparent on real. The observers often talk about subdwarfs, meaning objects that lie between the MS and the white degenerate dwarfs, or rather to the left of the upper main sequence and above the white dwarfs (in fact, to the left of most of them, as well as above). The subdwarfs are believed to be evolving to the WD stage, but still not completely degenerate. Or they can be "helium stars" lying on a helium main sequence – with anevolutionary past and future which is rather obscure. It is these objects we seem to find most frequently in the symbiotics. I wonder if Dr. Rudak can comment on their position and function in his models.

Rudak: The hot subdwarfs of O or B spectral types cannot be expected to be the members of symbiotic stars with shell nuclear burning, because of too low gravity ($\log g \sim 6.0$). I should not treat them also to be the progenitors of white dwarf components in symbiotics. The reason for this is that, according to Schönberner's calculations, they can become to be the helium-rich white dwarfs with relatively low masses well below 1 $M_\odot$. In nuclear burning models, very massive white dwarfs are necessary, if their envelopes are to be sensitive for any small changes in M_{env}.

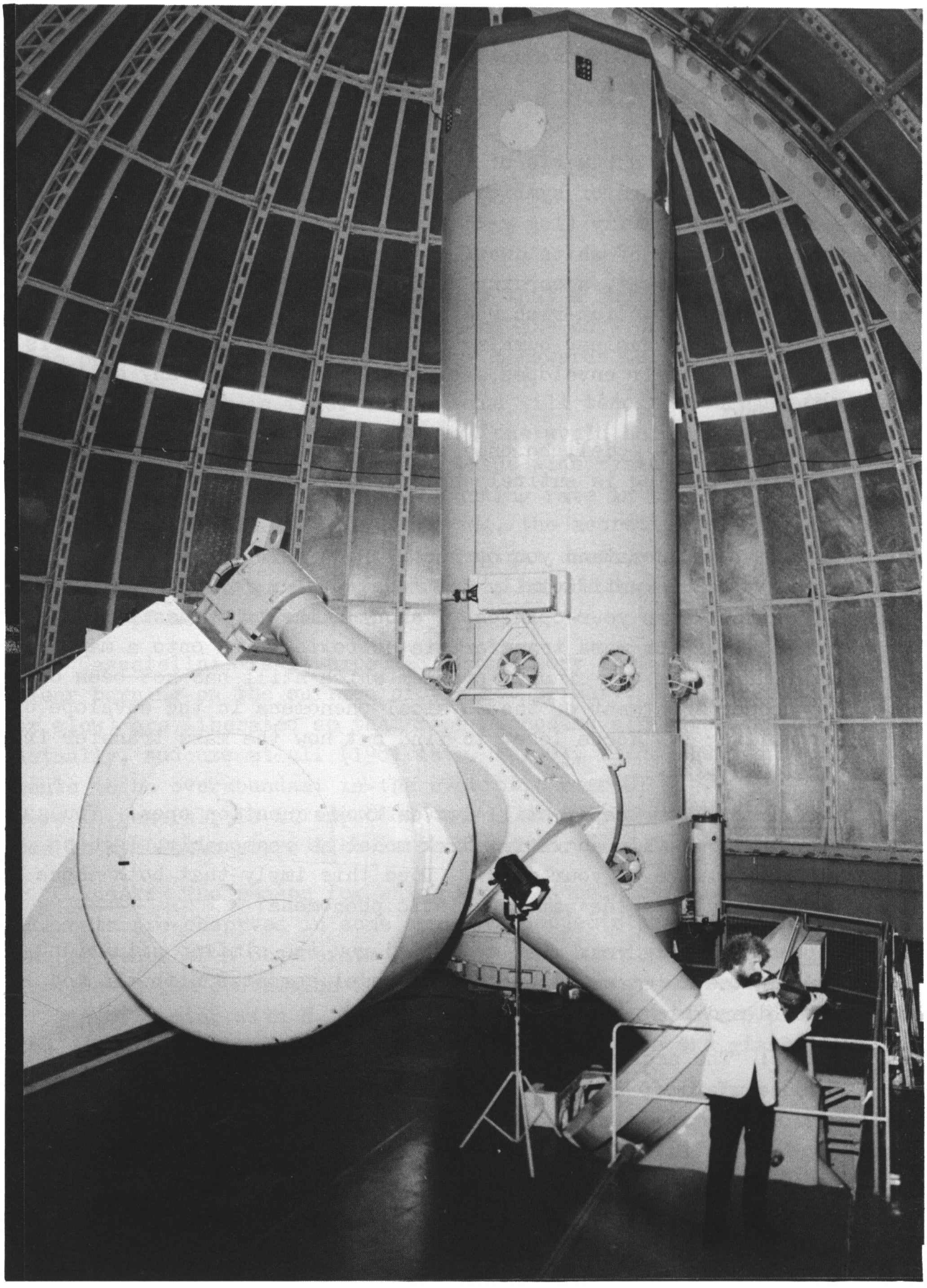
Kwok: In Bath's model, he only needs a UV continuum source and surface nuclear burning is entirely unnecessary. Would you comment on that?

Rudak: If I understand you correctly, you were considering nuclear burning models to be artificially too much complex for symbiotic phenomena? I do not share your opinion. I should like to emphasize that in "simpler" models, with mass transfer via accretion disk onto a main sequence star, there is one crucial problem which still has not been overcome: the proper treatment of the physical phenomena in the envelope of red giant filling its Roche lobe, to find out how the mass transfer from this star looks like.

Nussbaumer: Your reply still leaves Kwok's question open. You say that you consider Bath's accretion disk model as reasonable. I guess that you also believe in your model. Does this imply that both these models would result in the same symbiotic phenomena?

Rudak: Generally yes. Let me remind you the similar situation with classical novae stars, where Bath's model competes with the model of Starrfield and his collaborators.

Kafatos: The accretion model for symbiotic stars requires, I think, main sequence stars of $\sim 1\ M_\odot$. If the secondary is considerably smaller than a one solar mass main sequence star, then the inner regions are too hot and should give off soft X-rays.



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