1992RvMA....5...38L

Symbiotic Stars

R. Luthardt

Sternwarte Sonneberg, Sternwartestr. 32,
O-6400 Sonneberg, FRG

1. History

For about six decades symbiotic stars have played an important role in stellar astrophysics. The interest in these mysterious objects has been growing, especially since it became possible to observe in non optical wavelength ranges by satellites.

The history of symbiotic stars began with a notice in the Henry-Draper-Catalogue, where the spectral type of HD 221650 bears the attribute »peculiar« because of its outstanding spectral features. This star had already been known as the irregular variable star Z Andromedae. PLASKETT (1928) described it as having a »composite stellar and nebular spectrum«. He drew attention to emission lines of high excitation like those found in planetary nebulae and, at the same time a temperature estimated from the continuum of only about 5000 K.

1932 MERRILL and HUMASON (1932) reported in the PASP about a small number of stars which showed TiO-absorption bands in their spectra and, in addition, emission lines like HeII 4686, [OIII] 4363 and other nebular lines. They were the already known variable stars stars AX Per, RW Hya, CI Cyg, T CrB and R Aqr.

At first those stars were called »stars with combined spectra«. The term »symbiotic star« was first used in a publication about BF Cyg by P. MERRILL (1941). At that time it was not clear yet that these objects are really binary stars »living in symbiosis«.

At present more than 180 symbiotic objects are known (e.g. catalogue by ALLEN (1984b), VAIDIS (1988)).

Although there was great progress in symbiotic star research in the 50th and 60th (e.g. by MERRILL and BOYARCHUK) using optical data, a decisive step was done by satellite astronomy. Observations in non-optical wavelength ranges, especially in ultraviolet, make possible an unambiguous identification of a star as a symbiotic. IUE ,e.g., provided thousands of UV-spectra of symbiotic stars. But also from the infrared region there is a lot of observational material, in particular for studying the cool component of the system. Some symbiotics are also sources of radio- and X-ray radiation.

2. Criteria for symbiotic stars

As we said above, symbiotic stars are conspicuous for their outstanding spectrum. In some cases their emission line spectra remind to those of Planetary nebulae. The continuum, however, indicates a relatively low temperature and the absorption features mostly correlate with spectral type M, luminosity class II...III.

BOYARCHUK (1969) published the following criteria for classifying symbiotic stars:

1. Absorption lines of late spectral type (TiO-bands and low-excited metal lines) must be visible (CaI,CaII, FeI, FeII,..).
2. Emission lines of high excited ions must be present (e.g. HeII, OIII a.o.). The Doppler-broadening is not larger than 100 kms^{-1}.
3. A blue continuum must be visible.
4. Variation in brightness up to 3 mag and more is possible.

ALLEN (1978) made BOYARCHUK's criteria more precise by adding the following:

5. The object must be stellar-like.
6. Emission lines of high energy (55 eV and more) must be visible at times.
7. The spectral type must be later than G. If there is no indication of a late spectral type, excitation energies of more than 100 eV must be present sometimes at least.

In 1982 NUSSBAUMER added the following criterium:

8. It is difficult to classify the object as something else.

It became evident that several criteria will be broken now and then, especially in the transitional phase between quiescent and outburst stages.

3. Model of a symbiotic star

From photometric and spectroscopic observations BOYARCHUK (1969) assumed that symbiotic stars consist of three components:

1. A cool (M) giant of about 100 $R_\odot$,
2. A hot compact object - subdwarf or white dwarf - of less than 0.5 $R_\odot$ and an effective temperature of about 100 000 K. The distance between these components is mostly larger than 1000 $R_\odot$. Consequently the orbital periods of those systems range from about one up to several years.
3. The two objects are surrounded by a common gaseous or nebulous envelope: $R \approx 50\,000\, R_\odot$, $n_e = 10^6 ... 10^7$ e/cm^3, $t_e = 15\,000 ... 20\,000$ K.

Source of the common envelope is the red giant losing mass by stellar wind or by pulsation. The highly excited emission lines are produced in the vicinity of the hot compact component, which is a mass accretor. This is the reason for occasional activities like the occurence of outbursts (See fig. 1).

There were also single-star models, but they could not be maintained by the progress in modern observation.

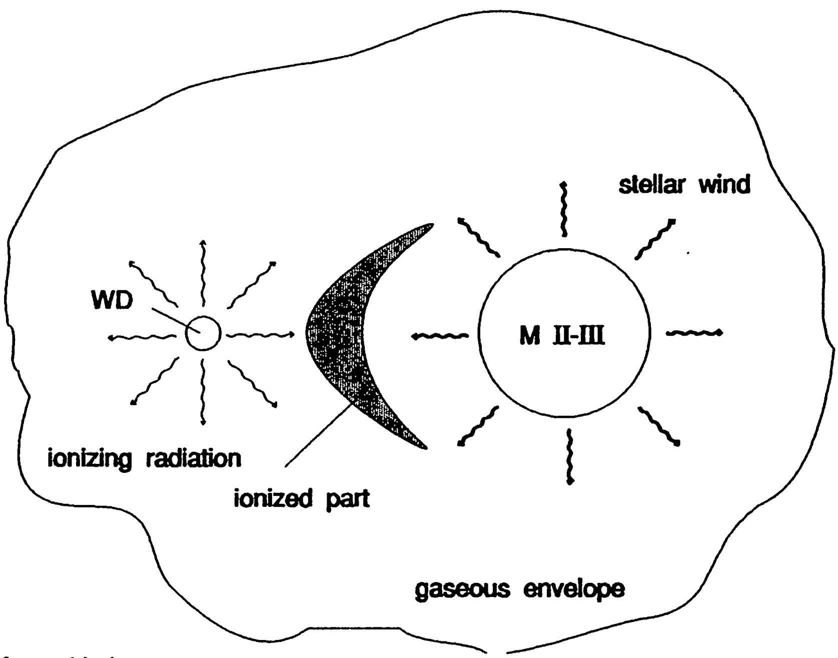

fig. 1. model of a symbiotic star

4. Number and space distribution of symbiotic stars

The number of stars known or suspected to be symbiotic is relatively small compared with the number of all known variables, which is about 40 000. Extrapolations arrived at an estimated number of about 20 000 symbiotics in the whole galaxy.

The majority of the symbiotic stars concentrate in the galactic plane, which is comparable with the distribution of red giants, galactic novae or planetary nebulae. This can be interpreted as an indication that symbiotic stars are members of the old disk population. In high galactical latitudes symbiotics are rather rare (AG Dra). Symbiotics have also been found in the Magellanic Clouds.

The relatively small number of symbiotic stars indicates that they are a short stage in stellar evolution.

5. Symbiotic stars in the optical wavelength range

5.1. Symbiotic stars as variable stars

Most (all?) symbiotic stars are also variable stars. The variations are almost irregular, or semiregular. There is no standard lightcurve for symbiotics, each object has its own individual one.

The following examples show lightcurves of typical symbiotic stars in the UBV system observed with the 60 cm-II-photoelectrical telescope of Sonneberg Observatory. About 20 symbiotics have been observed as often as possible with this telescope in recent years to study their long term behaviour. More detailed observations will be published in IBVS and in »Mitteilungen über Veränderliche Sterne«

Z And:

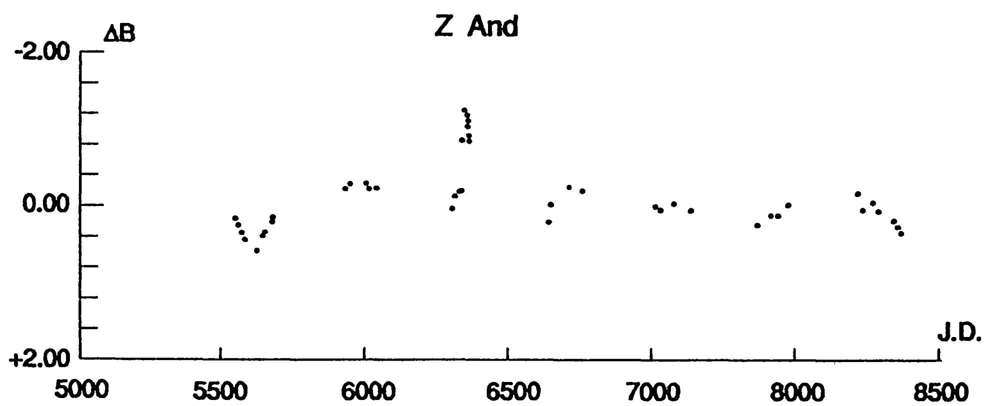

fig.2. B-lightcurve of Z And

The lightcurve shows semiregular changes of about 0.5 mag with a period of 760 days on average. This stage is interrupted by larger eruptions of an amplitude of about 4 magnitudes (see fig. 2). Change from longer quiescent stages (lasting sometimes for years) to a phase of activity - the outburst phase, is characteristic of symbiotic stars.

A good example of this behaviour is

AG Dra:

The first lightcurve contains photgraphic observations on plates of the Sonneberg Sky Patrol. With these plates (more than 230 000) it is possible to follow the long term behaviour of stars up to 14^{m} as far back as to the year 1925. The second lightcurve is obtained from photoelectrical observations in UBV.

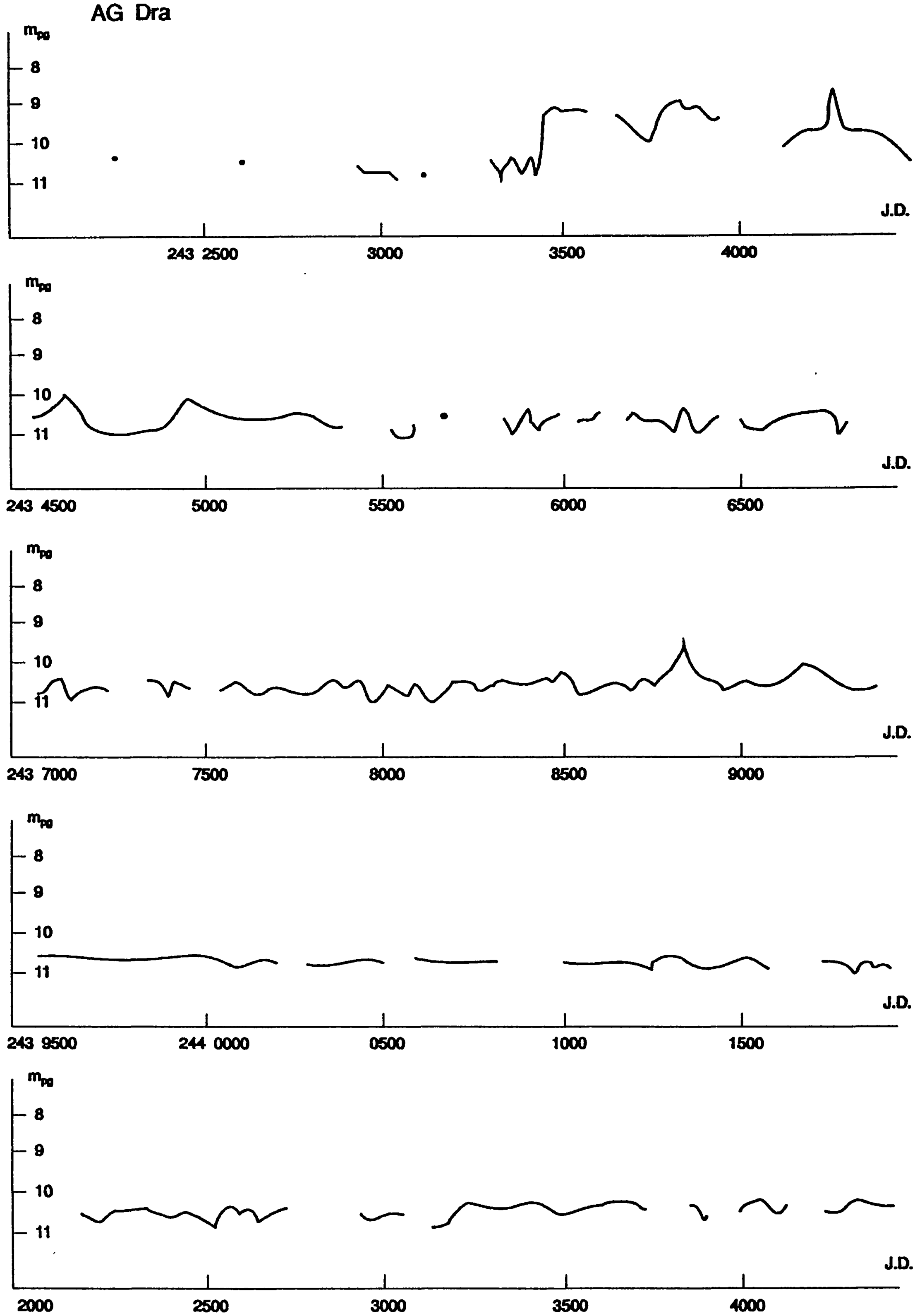

fig. 3. photographic lightcurve of AG Dra

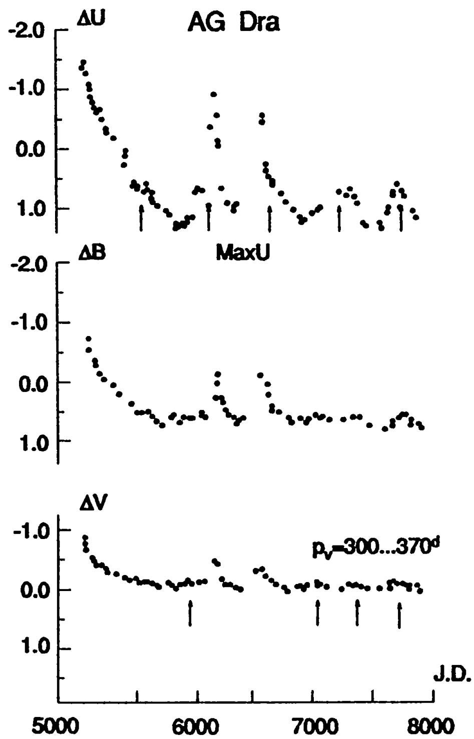

fig.4. UBV-lightcurve of AG Dra (1982-1989)

The variations of AG Dra:

A great outburst is mostly followed by smaller ones. In recent years this star has been in its quiet phase. In B and V the variations are unessentially small with a period of 300...400 days. in U, however, there are remarkable, regular variations with a period of 554 days (MEINUNGER 1979). These variations have also been continued after the great outburst in 1980/1981. The cause of this phenomenon is presumably occultation due to orbital motion of a hot spot generated by mass transfer in the system. The intensity maximum of the hot spot lies in shorter wavelength ranges.

Having different lightcurves at different colours is another typical feature of symbiotic stars.

EG And:

This star has almost no variations in B and V, but it shows remarkable variations in U. The calculated period is 476 days. Other but similar values were published by other authors: 492 days (GARCIA, KENYON 1988), 482.2 days (SKOPAL et al. 1990).

The variations probably have the same cause as in AG Dra. As yet outbursts of EG And are not known.

(see fig. 5)

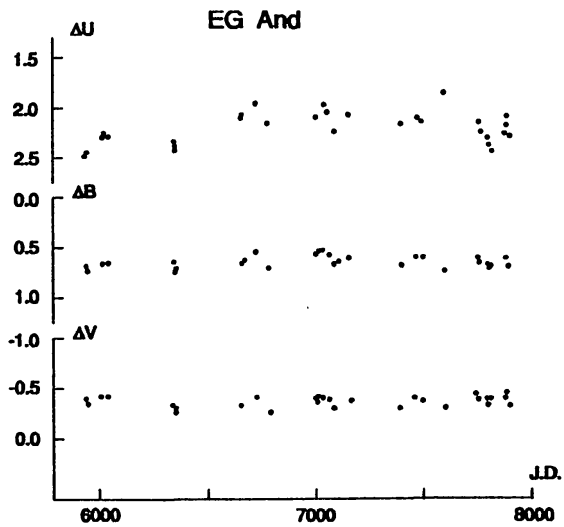

fig. 5. UBV-lightcurve of EG And

Contrary to those examples the behaviour of the next is quite different:

UV Aur:

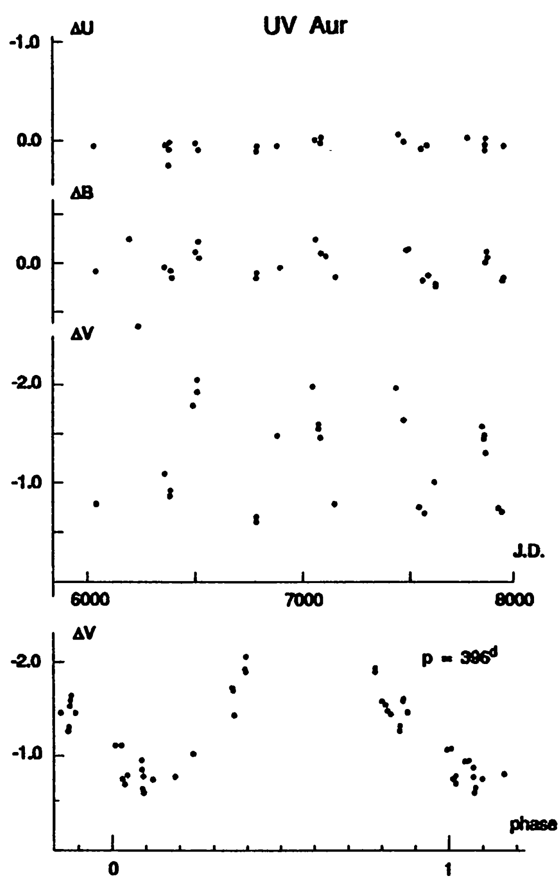

fig. 6. UBV-lightcurve and periodogram of UV Aur

No significant changes in U have been observed, but there are relatively regular variations in B and V. The period amounts to 396 days. Similar variations are in the infrared region (fig. 6).

This is an indication for a Mira type component (pulsations).

CI Cyg:

The star is an eclipsing symbiotic. For such objects, it is comparetively easy to find the correct orbital period. For CI Cyg it amounts to 856 days. In addition to the eclipses, there were larger eruptions in the past (fig. 7).

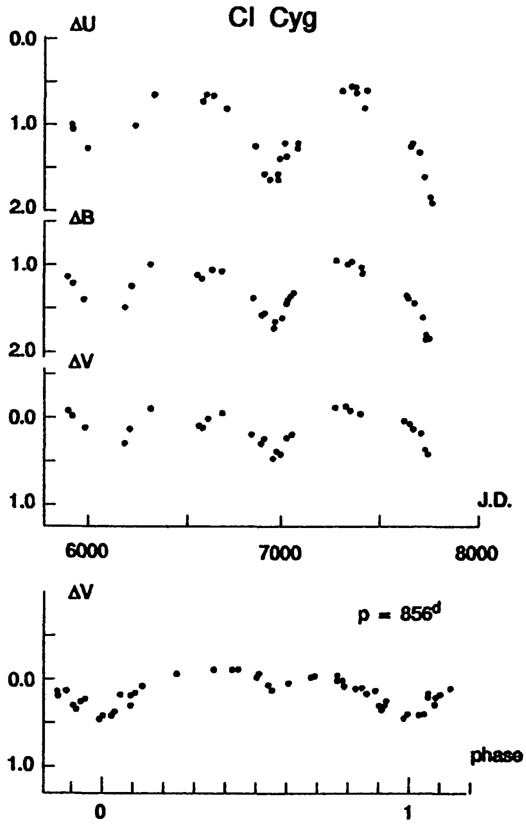

fig. 7. UBV-lightcurve and periodogram of CI Cyg

There is an outstanding group of symbiotics - the so called symbiotic novae.

A characteristic feature of these objects is a sudden rise in brightness over some magnitudes. The rise is however much slower than in classical novae. Its time scale is weeks up to several years. The decline following the maximum takes up to some decades, or even more. Therefore these objects are also called »very slow novae«.

A typical example is the following:

AG Peg:

Its outburst began in 1855 at a visual magnitude of 9^m. The star was in maximum in 1870 at about 5^m. The following decline has been very slow, the star is currently recovering its pre outburst brightness (fig. 8).

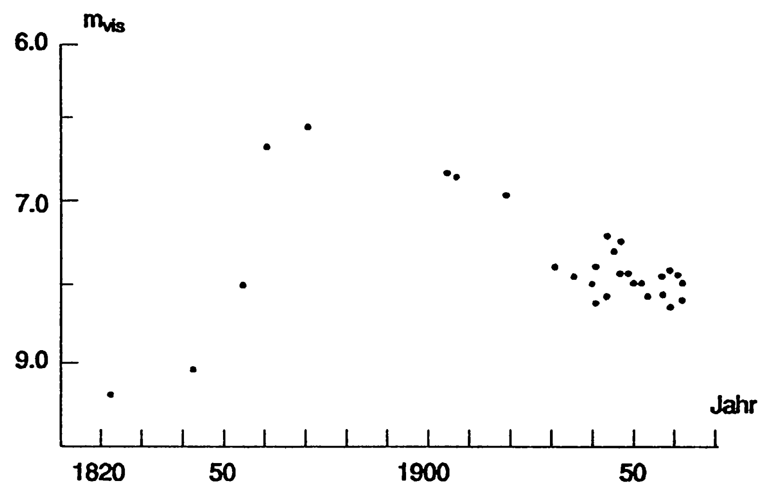

fig. 8. visual lightcurve of AG Peg

Other representatives of this group are RR Tel, V1016 Cyg, HM Sge, PU Vul.

5.2. The optical spectrum of symbiotic stars

Symbiotic stars show a combined spectrum. The following components are present:

1. Absorption spectrum of a late giant
2. highliy excited emission line spectrum
3. blue continuum

(see fig. 9)

The spectral features are very individual, too.

Simultaneous with the variations in brightness there are remarkable changes in the spectrum. The following correlations between variation in brightness and spectral variability are typical:

1. During maximum there are intensive emission lines of lower and high excitation. The spectrum is similar to that of planetary nebulae. The late M-type absorption spectrum and the blue continuum are also visible.

2. With brightness rising, the TiO-bands are becoming weaker. This is also the case with the emission lines of high intensity. The spectral features change to an early shell spectrum with a continuum dominating in the optical region and covering the M-spectrum.
3. During the maximum in brightness the nebular spectrum is missing. Only H, HeI, and sometimes [OIII] are visible in emission. H and HeI have P-Cyg-profiles.
4. The decline in brightness goes the opposite way. The shell features disappear, the blue continuum becomes visible again, also the emission lines and the M-absorption spectrum.

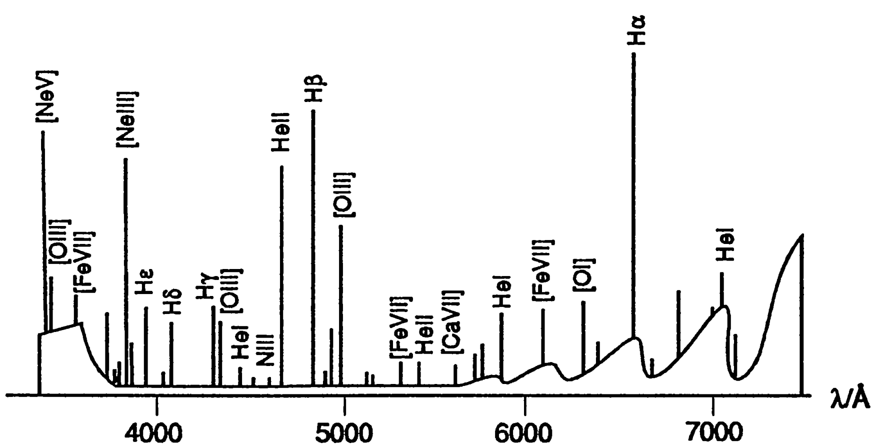

fig. 9. schematic spectrum of a symbiotic star

Some objects show remarkable profile variations over one period: e.g. at Hα turning from emission into absorption at EG And. These variations are correlated with the orbital period (KENYON 1986).

AG Dra plays an outstanding role in its spectroscopical features. The prime component is not of spectral type M but of type K. Besides the Balmer emission lines we find HeI, HeII a.o.

Quite different are the symbiotic novae, confirming their outstanding role:

(Mostly) no continuum in the optical range, a great number of highly ecxited emission lines, no M-absorption spectrum is visible. The spectral features also vary during the evolution of the nova.

For example AG Peg:

The outburst occured between 1855 and 1870. The brightness increased from about 9^m up to 5^m.

In 1894 H-emission lines with P-Cyg profiles were found on objectiv prism plates. This led to the assumption that there is an extended envelope. Up to 1912 no significant spectral variations were detected. From about 1920 the spectral features have changed strongly. With dominating Balmer emission lines and HeI absorption lines the spectrum looked Be-like.

With progressing time the HeI-absorption lines became fainter and and turned over into emission lines. Simultaneously a lot of emission lines of different intensity appeared. Up to 450 lines of this kind were present in the range λ = 3000...6000 Å. Also a typical M-absorption spectrum grew up. The TiO-band appeared in about 1930. HeII 4686 and NIV became the dominating emissions. The typical nebular lines appeared in the 40th, in the 50th also forbidden lines like [OIII] and [NeIII] became visible.

AG Peg showed the typical properties of a symbiotic star (MERRILL 1959).

Measurements of radial velocities mostly show periodical variations with cycle length of several hundred days up to years. In most cases the emission lines are phase shifted to the M-absorption lines. This also confirms the binary nature of the system.

6. Symbiotic stars in the infrared

Because of the late spectral type the infrared region might provide important information.

Observations show that symbiotics divide into two groups in the infrared light:

Symbiotics with dust emission in the region 1...4 μm:

D-type symbiotics (dust) and

objects without these characteristics:

S-type symbiotics (stellar).

In D-types dust emission predominates while in S-types the infrared emission of the red giant is the dominant feature. While most of the D-types the giant is not, or only with difficulty detectable in the optical region, but well detectable at 2.3 μm in the infrared. Mostly the D-type symbiotics are also Miras. The S-types in general show no variation in the infrared.

7. UV observations of symbiotc stars

Observations in the ultraviolet region became possible by employing satellites like IUE. It opened a new era in symbiotic star research.

Since than it has been known that symbiotics are very bright ultraviolet sources. This brightness confirms the presence of a hot component, which had already been inferred from the optical data. There are a very rich emission line spectrum and a strong continuum. HeII, CIII], CIV, SiIV and NV are the dominating emission lines.

On the basis of UV observations the classification of symbiotic stars is unambiguous. Uncertainties about objects which look similar in the optical range (e.g. some VV Cet stars) can be dispelled by clear distinctions in the UV.

8. X-ray observations

Because of the high temperature of the hot component it has been assumed that most of the symbiotics are soft X-ray sources at the very least. But to this day the results of X-ray observations have been disappointing. Today AG Dra is the only symbiotic star where X-rays have been detected. But this object, however, is a singular case on account of its K-component.

Symbiotic novae were at first expected to emit X-rays, but only in few objects of this class it has been detected (e.g. HM Sge).

It is assumed is that a large amount of X-ray emission is lost owing to interstellar absorption (H regions between the star and the observer).

More and better results are expected from the ROSAT mission.

9. Radio emission

By reason of the extensive nebulous envelope and mass streams between the components symbiotic stars are assumed to be radio sources.

Radio emission has been detected with V1016 Cyg, V1329 Cyg and HM Sge, also with RX Pup, AG Peg RR Tel a.o.

Especially D-type symbiotics should be candidates for radio emission. These objects were assumned to emit OH- and SiO-maser radiation. But observational results proved negative. The maser mechanism detected in many long periodic miras is possibly suppressed by the hot component in symbiotic stars (WHITELOCK 1987). On the other hand radio emission could be detected with S-type symbiotics during their quiet stage.

10. The two stages of symbiotic stars

There are two main stages of activity for symbiotic stars:

- the quiet phase
- the outburst phase

During the quiet phase only small semiregular variation with amplitudes of some tenth of magnitude are existent. This »low stage« of activity is interrupted by sudden eruptions or major outbursts. Amplitudes of up to 5 or more magnitudes are possible. For smaller eruptions (up to 1...2 mag) the rise in brightness, and also the decline, is a matter of days or weeks. For »normal« symbiotic stars the outburst phase takes up to several years and includes various eruptions or outburst. Greater outburst are mostly followed by smaller eruptions. (e.g. Z And, AG Dra, BF Cyg a.o.).

Symbiotic novae have, after a long quiescent phase, a great outburst with an amplitude of several magnitudes. The rise is much slower than in classical novae - it takes a few months up to several years. The decline goes very slowly. The star reaches its pre outburst brightness after some decades, in some cases after about 100 years.

10.1. The quiet phase

BOYARCHUK was one of the first to calculate models of individual symbiotic stars and compare them with observational (optical) data. For the hot component he assumed blackbody radiation with an effective temperature of 10^5 K, for the ionized nebula 17000 K and an electron density of $10^6/cm^3$. The emissions should be caused by recombination. The nebula was assumed to be optically thick for $\lambda < 912$ Å and optically thin for $\lambda > 912$ Å.

The models reproduced the observations in the spectral range $\lambda = 3200...8000$ Å well for several systems.

Long term variability in, e.g., Z And and AG Peg is caused by variations in the effective temperature of the hot component, but at constant bolometric luminosity.

The UV-satellites gave the basis for detailed spectrophotometrical investigations in wavelength ranges down to 1200 Å. The theoretical models were subsequently be tested in the ultraviolet region.

KENYON and WEBBINK (1984) improved the models of BOYARCHUK. They assumed that two types of the hot component are possible:

1. a hot compact star, similar to central stars in planetary nebulae
2. a white dwarf or main sequence star with an accretion disk

Models calculated were based on the following assumptions:

1. an M2III-star, surrounded by an ionised nebula with $T_{eff} = 10^6$ K; a white dwarf with $R = 0.01 R_\odot$, separated from the giant by about $10 R_\odot$.

These models were calculated for different values of t_{eff}.

At low temperatures of the hot dwarf the M-spectrum dominates, the white dwarf spectrum is very weak. With increasing temperature the intensity of the UV-spectrum increases too.

T_{eff} = 100 000 K: HeII 1640 strong, weak Balmer-jump at λ = 3646 Å, optical emissions weak.

T_{eff} = 200 000 K: HeII 1640 very bright, jumps at λ = 2052 Å and 3646 Å. The optical spectrum does not differ from the M-spectrum, except of the emissions.

2. A main sequence star as the accreting component, $M = 1\,M_\odot$, $R = 1\,R_\odot$.

Calculations were made for different accretion rates.

For low accretion rates ($10^{-7}\,M_\odot$ / yr) the optical spectrum does not differ from normal M-spectra. The UV-spectrum is weak, the nebular lines are the result of photon emission at the optically thick boundary layer at the disk frontier (For these mass rates invisible, the star looks rather like an Me-star than a symbiotic).

Accretion rate $3 \cdot 10^{-7}\,M_\odot$ / yr:

Nebular and Balmer emission lines appear nearly with the same intensity.
The blue emission lines increase with the accretion rate, and so does the blue continuum.

For accretion rates near the Eddington limit ($10^{-3}\,M_\odot$ /yr) the continuum is dominated by the accretion disk, the M-spectrum is missing. Indeed for such accretion rates the Roche lobe must be filled.

The situation is quite different, if a white dwarf of $1\,M_\odot$ takes the place of the main sequence star.

Then weak Balmer emission lines and also HeII are already visible in the optical range for low accretion rates. The intensities increase with rising accretion rates. The Balmer jump is a remarkable indicator of white dwarfes as accreting component. For medium accretion rates ($10^{-8}\,M_\odot$ /yr) the UV-spectrum is similar to those of black body radiator models. At the Eddington limit ($10^{-5}\,M_\odot$ /yr) the absorption features become prominent. The nebular emission spectrum is wery strong, the emission lines are broad.

Radio emission:

From the radio continuum it is possible to obtain information about the hot component because the radio flux density should be correlated with the nature of the ionizing source. Continuum emission is expected to be thermal bremsstrahlung in the radio frequency region. Since the radio emission depends on the extension of the nebula, radio emission is not supposed to come from symbiotics with small dense nebula. Systems with giants filling the Roche lobe and with extensive accretion disks do not have extensive nebula beyond the orbit. The calculated flux lies below the present detection limit.

Objects with red giants losing mass by stellar wind are expected to have extensive nebulae. They would be »bright« radio sources.

10.2. The outburst phase

In contrast to its its small irregular or semiregular variations in the quiet phase, brightness variations in the outburst phase covers several magnitudes. Also the spectrum shows remarkable changes, as has already been noted. A striking feature are P-Cygni profiles at the emission lines. The spectrum alters and assumes features observed in early type stars (A...F-type). Some objects appear as Wolf-Rayet-stars. All these features indicate mass flow by stellar wind.

Theory:

The outburst mechanism for symbiotic stars was at first explained on the basis of models for classical or dwarf novae. For the hot component TUTUKOV and YUNGELSON (1976) proposed a white dwarf with a steady hydrogen shell maintained by material coming over from the red giant by stellar wind. Small fluctuations of the accretion rate lead to variations in the properties of the shell and are responsible for outbursts. The properties of a symbiotic system depend on the following parameters:

1. mass loss rate of the red giantg
2. separation of the components

The mass loss rate of such objects is estimated at 10^{-7} ... 10^{-5} $M_{\odot}$ /yr. Larger rates may cause dust formation, lower rates do not generate such emission lines as are visible in symbiotic stars.

The distance between the components is about 2 ... 20 AU. For a total mass of the system of 2...3 $M_{\odot}$ orbital periods amount to between 1...50 years. In D-type symbiotics, periods may be longer.

PACZYNSKI and RUDAK (1980), PACZYNSKI, ZYTKOW (1978) and also KENYON and TRURAN (1983) used those models for calculating individual systems.

One distinguishes between two categories of outbursts:

1. spontaneous (short) outburst (Type-I)
2. slow nova outbursts (Type-II)

For Type-I symbiotics the presence of a white dwarf with a stable hydrogen burning shell is assumed. Outbursts are the result of variable accretion rates.

For Type-II symbiotics the accretion rate onto the white dwarf lies below a critical amount for steady hydrogen shell burning. Outbursts are caused by hydrogen shell flashes. Fast decreases in brightness need lower shell masses, but high L_{on}-luminosities.

The explanation is given by PACZYNSKI and RUDAK:

The white dwarf has a degenerated core. There are two critical accretion rates $\dot{M}c1$ and $\dot{M}_{c2}$.

The larger one ($\dot{M}_{c1}$) is the upper limit for hydrogen shell burning. By this amount hydrogen-rich material is burning in the shells of degenerated cores (red giants). At $\dot{M}_{c2}$ the hydrogen burning becomes instable.

Reaching $\dot{M}_{c1}$ the shell expands after an initial shell flash, and the star looks like a supergiant. Is has a degenerated core and a hydrogen-burning shell.

For accretion rates less than $\dot{M}_{c1}$, stable burning is possible. Shell mass, radius and T_{eff} depend on the core mass mc and the accretion rate. For lower accretion rates, radius and shell mass are small, T_{eff} is higher.

If the accretion rate drops below $\dot{M}_{c2}$, the shell burning becomes unstable, irregular variations in brightness or smaller outbursts with more or less regular period are the result.

Calculations lead to:

$$\dot{M}_{c2} = 0.4\,\dot{M}_{c1}$$
$$\dot{M}_{c1} = 2.8 \cdot 10^{-7} + 5.9 \cdot 10^{-7}\ (M_c/M_\odot - 1)$$
$$L/L_\odot = 28320 + 59250\ (M_c/M_\odot - 1), \quad (M_c : \text{core mass})$$

For decreasing accretion rates the shell flash intensitiy increases and the period becomes longer. It amounts to about 1 year if $\dot{M}ac = \dot{M}_{c2}$ and $M_c = 1.4\ M_\odot$.

Longer flash periods are caused by small core masses and small accretion disks. Very small accretion rates lead to gradual mass cumulation ending in a nova outburst.

At high accretion rates also He-shell burning is possible. He-burning is thermally unstable. The period of He-flashes is longer than that of H-flashes. For accretion rates below $\dot{M}c2$, one He-flash is expected after about 50...1000 H-flashes. For $\dot{M}ac > \dot{M}_{c2}$, it is assumed that there are only He-flashes.

Type-I-symbiotics:

The prototype is Z And. PACZYNSKI and RUDAK (1980) described it as follows:

The accretion rates vary between $\dot{M}c1$ and $\dot{M}_{c2}$ on a time scale of months up to years. After a flash, hydrogen burning may be stable for a longer time. He-flashes may occur from time to time. The period between them may be very long. A variable accretion rate causes variations in shell mass, radius and temperature. The variation in Teff may be very large, but at constant bolometric luminosity.

For a typical symbiotic system the following parameters are assumed:

$M_{hot} = 1 M_\odot$
$A = 1000\ R_\odot$
$p = 600^d$
$\dot{M}_{lost} = 10^{-5}\ M_\odot$ /yr
$\dot{M}_{ac} = 10^{-7}\ M_\odot$ /yr (LAMERS et al. 1976)

The shell mass is negligible in comparison with M_{core}. Small variations lead to large variations in T_{eff} and R_{hot}. The results are variations in magnitude of up to 3 mag (for $\Delta M_{env} = 4 \cdot 10^{-7}\ M_\odot$).

Candidates: Z And, (AG Peg), AG Dra, CI Cyg, BF Cyg, AX Per

Type-II-symbiotics:

Before the outburst these stars appear as long-periodic variables with low excited emission lines. The outburst amplitude can reach about 5 mag and more. The excitation potential rises quickly.

Great progress in this field was made by the contributions of NUSSBAUMER (1990) and NUSSBAUMER and VOGEL (1990).

They pointed out, as has also been assumed by PACZYNSKI and RUDAK, that nuclear fusion on the surface of the white dwarf is the most possible energy source for symbiotic novae. Gravitational energy as a source of the high luminosities of the hot component is not sufficient, as calculations show (10 $L_\odot$ only). Luminosities of about 1000 $L_\odot$ and effective temperatures of 100 000 K were observed. This shows that accretion is not the energy source, but it provides the material for it.

IUE-observations have confirmed that symbiotic novae are indeed novalike systems.

Remarkable results for outburst models of symbiotic novae were published by LIVIO et al. (1989). It could be shown that for slow outbursts over a period of time of about 20 years and more accretion rates of 10^{-8}... $10^{-6}\ M_\odot$ /yr are good values.

During the outburst the shell absorbs energy generated by nuclear fusion and therefore expands. This expansion can lead to mass ejection by an optically thick wind or to an extended envelope respectively. This envelope loses mass because of mass ejection or nuclear burning. After the nuclear burning the star returns to its pre outburst-stage.

The assumed mechanism taken as a basis, the main problem with symbiotic novae or symbiotic stars in general is accretion.

Before the outburst the material must be provided by the cool component by mass loss.

The question is weather a sufficient amount of material will reach the white dwarf. Because of the large separation of the components in those systems Roche overflow is mostly impossible. Only wind accretion may be the ongoing mechanism for mass transfer. But there are also a number of problems, e.g. are there magnetic fields? what role do they play? a.s.o.

10.3. Relation between the hot and cool component

The symbiotic phenomenon does not appears in a binary systems unless several parameters come together, and the values of these parameters admit only very narrow variations:

PACZYNSKI und ZYTKOW (1978) showed that stable hydrogen burning can only be maintained in a very narrow range of the accretion rate. At larger values the shell would expand and the system become a red giant. The possible rates lie between $1 \cdot 10^{-7} ... 3 \cdot 10^{-7} M_{\odot}$ /yr. The resulting effective temperature also depends on the accretion rate.

This process may be going on in Z And and similar objects.

Mass accretion and fluctuations of it may directly influence the nuclear burning on the surface of the white dwarf and appear respectively as variability in brightness or fluctuations of the surface temperature.

Variable accretion rates may be caused by elliptical orbits, variable mass loss of the red giant a.o.

Variable mass loss may also directly cause fluctuations in the brightness of the system. This is explained by NUSSBAUMER and VOGEL (1990) as follows:

The cool stellar wind from the red giant interacts with the photons of high energy of the hot component, turning UV-photons into visible light. At faint winds the conversion is weak and vice versa. Calculations show that variations in mass flow of 10^{-8} und 10^{-6} $M_{\odot}$ / yr lead to variations in brightness of up to about 4 mag.

In some systems two winds are assumed, one from the cool, one from the hot componenet. Radio emission results from this interaction.

11. The position of symbiotic stars in stellar evolution

Certainly symbiotic stars represent a late evolutionary state of binary systems. Because of their rareness this state must be of very short duration or not passed through by every close binary systems, or both.

For all the differences in the individual systems, they have one thing in common - the evolved red giant, which is really a very short episode in the evolution of a star lasting about 10^{-6} years.

The second component admits of both variants - white dwarfs or subdwarfs - but also low mass MS-stars are possible. Massive main sequence stars however, evolving faster than the primary component, cannot be candidates for the secondary component. Moreover, it is assumed that the total mass of a symbiotic system is not larger than 2 ... 3 $M_\odot$. We also believe that symbiotic stars are not a very outstanding class of stars, and that their evolution takes place within the limits of the normal mechanisms of stellar evolution of binary systems with periods larger than 100 days. Since this group of stars is inhomogenuous, there are different ways of evolution possible.

The following mechanisms are proposed:

The orbital period of the system is an important parameter for the evolution of a symbiotic star. For periods of 50 ... 100 days and a primary component of 1 ... 3 $M_\odot$ it reaches its Roche lobe before the transition into the giant stage. Therefore mass will flow via Lagrange point onto the secondary component. The system becomes a normal (semidetached) contact system. - Binary stars with periods longer than 100 days can become red giants, but, if the period is shorter than 5000 ... 10 000 days, they too will reach the Roche lobe in the course of their evolution. Calculations show that the mass loss can come up to a rate of 10^{-6} $M_\odot$ /yr and than symbiotic features would appear. After this giant stage a second symbiotic period can set in, if the secondary component evolves into a red giant. Then mass flows to the old primary component, which is now a white dwarf. The symbiotic phenomenon appears if the accretion rate reaches 10^{-9} $M_\odot$ /yr at least.

If periods are longer than 5000 ... 10 000 days the Roche lobe will never be filled up. Mass loss is only possible by stellar wind. Only a small part, about 1%, may be accreted by the compact component, which means accretion rates of 10^{-7}... 10^{-9} $M_\odot$ /yr.

With main sequence stars, accretion rates of 10^{-5} $M_\odot$/yr are necessary for the symbiotic behaviour. Degenerated objects require only 10^{-9} $M_\odot$ /yr, which is the reason why, in such widely separated systems, the secondary component has to be a degenerated star.

12. Concluding remarks

It is necessary to make further observations on a large time scale and in all wavelength ranges. We need to know exact orbital elements of the systems because there are still many differences. Therefore a sufficient number of radial velocity measurements have to be made, exact photometric data obtained, etc.

All the new telescopes and satellites will certainly contribute to our understanding of these interesting objects.

References:

Allen, D.A.: 1979, in IAU-Coll. No. **46**, ed. F.Bateson et al. (Hamilton, N.Z.: U.Waikato Press), 125
Allen, D.A.: 1984, Astrophys. Sp. Scie. **99**, 101
Allen, D.A.: 1984, Proc. Astr. Soc. of Australia, **53**, 369
Boyarchuk, A.A.: 1969, in Non Periodic Phenomena in Variable Stars, ed. L.Detre (Budapest:Academic Press), 395
Garcia, M.R., Kenyon, S.J.: 1988, in IAU-Coll. No. **103**, The Symbiotic Phenomenon, ed. J. Mikolajewska and M. Friedjung (Dotrecht, Kluwer), 27
Kenyon, S.J. and Truran, J.W.: 1983, Astrophys. J., **273**, 280
Kenyon, S.J. and Webbink, R.F.: 1984, Astrophys. J., **279**, 252
Kenyon, S.J.: 1986, The Symbiotic Stars (Cambridge Univerity Press, Cambridge/Mass.)
Lamers, et al.: 1976, Astr. Astrophys., **49**, 327
Livio, M. et al.: 1989, Astrophys. J., **341**, 299
Luthardt, R.: 1983, Mitt. veränd. Sterne **9.5**, 129
Luthardt, R.: 1985, Inf. Bull. Var. Stars No. **2789**
Luthardt, R.: 1987, Inf. Bull. Var. Stars No. **3075**
Luthardt, R.: 1990, Contr. Astr. Obs. Skalnate Pleso **20**, 83
Meinunger, L.: 1979, Inf. Bull. Var. Stars No. **1611**
Merrill, P.W. and Humason, M.L.: 1932, Pub. Astr. Soc. Pac., **44**, 56
Merrill, P.W.: 1959, Astrophys. J., **129**, 44
Merrill, P.W.: 1941, Pub. Astr. Soc. Pac., **53**, 121
Nussbaumer, H.: 1982, in IAU-Coll. No. **70**, The Nature of Symbiotic Stars, ed. M. Friedjung and R.Viotti (Dotrecht: Reidel), 85
Nussbaumer, H. and Vogel, M.: 1990, in ESA Sp. **310**, 87
Paczynski, B. and Rudak, B.: 1980, Astr. Astrophys., **82**, 349
Paczynski, B. and Zytkov, A.: Astrophys. J., **222**, 604
Plaskett, H.H.: 1928, Publ. Dominian Astrom. Obs., Victoria, **4**, 119
Skopal, A. et al.: 1988, in IAU-Coll. No. **103**, The Symbiotic Phenomenon, ed. J. Mikolajewska and M. Friedjung (Dotrecht, Kluwer), 289
Skopal, A. et al.: 1990, Contr. Astr. Obs. Skalnate Pleso **20**, 113
Tutukov, A.V. and Yungelson, L.R.: 1976, Astrofizika, **12**, 21
Tutukov, A.V. and Yungelson, L.R.: 1982, in IAU-Coll. No. **70**, The Nature of Symbiotic Stars, ed. M. Friedjung and R.Viotti (Dotrecht: Reidel), 283
Vaidis, J.P.: 1988, Bull. A.F.O.E.V. **1988/3, 4, 1989/2**
Whitelock, P.A.: 1987, Pub. Astr. Soc. Pac., 99, 573