MODELS FOR SYMBIOTIC STARS IN THE LIGHT OF THE DATA

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ABSTRACT

Different single and binary models of symbiotic stars are examined. Single star models encounter a number of problems, and binary models are probable. There are however difficulties in the interpretation of radial velocities. Accretion disks play a role in some cases, but winds especially from the cool component must be taken into account in realistic models. There is some evidence of excess heating of the outer layers of the cool component. Outbursts may be related to sudden changes in the characteristics of the cool star wind.

I. INTRODUCTION

Doubts can be raised as to whether a class of "Symbiotic Stars" really exists, and it is far from clear that all stars so classified have the same physics. Therefore one can even ask whether it is justified to talk about models for these stars! In this review I shall mainly concentrate on the "Classical Symbiotic Stars", which do appear to have certain common features.

The objects upon which this review will especially be centred, possess in quiescence a composite spectrum, with a component apparently due to a cool giant usually combined with a hot continuum which tends to dominate at short wavelengths, and always emission lines including at some times some of very high excitation (NV, FeVII, etc.). In active phases brightening occurs, with the cool continuum tending to be veiled by a hotter one, while the high excitation emission lines disappear. Certain "Symbiotic Stars" such as V1016 Cyg, however may not completely satisfy this description.

Other features which are basic for any model, include the cyclic spectroscopic changes of period $10^2 - 10^4$ days, as well as the periodic photometric variations sometimes detected, which in a few cases (CI Cyg,

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and AR Pav at least) are best interpreted as due to eclipses. Different characteristics will be discussed later.

Various quite different models can be proposed for the "Classical Symbiotic Stars" as well as for related objects. These models will now be described and criticized.

II. SINGLE STAR MODELS

A number of attempts have been made to model symbiotics on the basis of single stars possessing outer layers having different regions with very varied physical conditions. Two general types of single star model exist:

(a) Hot central object surrounded by cool envelope.

Several suggestions of this nature for stars related to the symbiotic class have been made. For instance, Sobolev (1960) considered that cool stars with emission lines such as symbiotic stars could have a hot nucleus surrounded by an envelope with a significant optical thickness in some subordinate continua like the Balmer continuum, giving rise to the cool absorption spectrum. A similar model for V1016 Cyg has been recently proposed by Nussbaumer and Schild (1981), according to which it could be a young planetary nebula with the region where hydrogen is ionized having a mass of 3×10^{-4} $M_{\odot}$, surrounding a hot star with $T_{*} = 1.6\times10^{5}$°K and $R_{*} = 0.06$ $R_{\odot}$. Other single star models for this object exist (for references to them see Nussbaumer and Schild).

The observed properties of classical objects do not appear to fit this type of model. A cool envelope could be cool regions of a wind from a hot subdwarf, but then a wind velocity of the order of the stellar escape velocity ($\sim 10^{3}$km s^{-1}) of the type of star required would be needed. Neither emission lines with a corresponding width nor absorption lines with a corresponding blue shift are usually observed, AG Peg perhaps being an exception. In addition both line and continuum absorption of the hot continuum by the cool envelope might be expected unless there were large deviations from spherical symmetry. No sign of non interstellar excited neutral absorption lines has been reported in high dispersion ultraviolet spectra, though Johnson (1981) considers that continuum absorption by amorphous silicate smoke may occur in the ultraviolet of R Aqr. However as pointed out by Johnson this may be explained by a binary model, with absorption of hot component radiation by the cool star's wind. Even when low excitation lines are seen in the near-ultraviolet, they do not appear to be associated with the spectrum resembling that of a cool star. For instance Faraggiana and Hack (1971) found that the M6III star type absorption spectrum of CH Cyg was veiled by the blue continuum present in 1967.

Absorption of the hot continuum might be less important if there were deviations from spherical symmetry, such as in the model proposed by Menzel (1969) for certain stars, with a cool ring formed by a magnetic field around the hot star. However the cool component seen in symbiotic stars appears fairly normal, and often non variable as in the case of Z And (Altamore et al. 1979). Also no magnetic fields were detected by Slovak (1978) for symbiotic stars.

These objections would be less strong for models like that of Nussbaumer and Schild for V1016 Cyg and similar stars. An envelope could have been ejected from a previously existing red giant with a lower escape velocity, the giant having become a hot subdwarf following formation of the nebula as in the mechanism of Kwok et al. (1978). In the model the hot star does not give rise to more than half the ultraviolet continuum except below 1600 A.

(b) Cool central object surrounded by hot envelope.

Most normal stars appear to be surrounded by chromospheres/coronae, which are hotter than the visible photosphere. It is therefore attractive to consider an enhancement of this process, which would lead to emission lines formed in these layers being seen in the visual region, and not only in the far ultraviolet and beyond. Models of this type have been popular in recent years among certain astrophysicists inspired by far UV and X-ray observations of normal stars, and by theories of chromospheres and coronae. Such models were first proposed by Aller (1954) and considered in more detail by Gauzit (1955). One precise suggestion of this kind was made by Wood (1974), who considered relaxation oscillations of an asymptotic branch star producing shock fronts, which dissipate energy in the expanding envelope.

A major problem of such models, is to produce a hot optically thick region responsible for the hot continuum. Symbiotic star spectral energy distributions have been decomposed into a hot optically thick component, a hot gas component, a cool stellar component, and sometimes dust emission, starting with the classical work in the visual region by Boyarchuk (1966, 1967, 1968) on AG Dra, AG Peg and Z And. Since then hot continua have been found in the ultraviolet for various symbiotic stars by for instance Hack (1979), Gallagher et al. (1979), Keyes and Plavec (1980), Johnson (1980), Kafatos et al. (1980), Slovak (1981), and by Altamore et al. (1981). The last authors show that the gas producing the high excitation emission lines seen in the ultraviolet was probably not responsible for the hot continuum.

One could always imagine a hot continuum formed in heated optically thick spots of the stellar photosphere resembling solar faculae, but such a hypothesis seems somewhat artificial. A model of this sort involving magnetic heating was proposed for CH Cyg by Wdowiak (1977). However upper limits to coherent magnetic fields of 200 G were found for CH Cyg, AG Peg and EG And by Slovak (1978).

In addition the radial velocities of AG Peg characteristic of a double lined spectroscopic binary, and what are probably eclipses seen for other objects, are hard to explain with a single star model. To summarize it is hard to rigorously disprove the hot single star envelope model for all symbiotic objects, but it offers a physically less fruitful and more arbitrary approach than the models to be now discussed. However as will be seen certain features of the models just considered, probably need to be combined with the binary approach.

III. BINARY MODELS

None of the partecipants at the "North American Workshop on Symbiotic Stars" held in June 1981 in Boulder, defended a single star model for any symbiotic object. The binary star conception seemed to be unanimously accepted!

Binary models were as far as I am aware first proposed by Berman (1932) for several stars and by Hogg (1934) for Z And. It is clear that certain features of symbiotic stars, such as the composite spectral energy distribution, the cyclic spectral and photometric variations, the latter in some cases been very probably eclipses, very strongly indicate that these stars are binary. Binary models are for instance described in the reviews of Boyarchuk (1969, 1974). Many often complex processes are known to occur in interacting binaries, and the different properties of binaries which may be relevant will now be considered.

(a) Radial velocity variations.

Radial velocity variations usually differ considerably from those of a non interacting binary, and their interpretation poses perhaps the greatest difficulty for binary models. Let us consider some specific stars.

As shown by Cowley and Stencel (1973), AG Peg is a double lined spectroscopic binary. Visual region emission lines of highly ionized ions come according to these authors from regions near the hot star, but other emission lines come from other regions, and can in some cases be perturbed by violet shifted absorption. A more detailed model for this star involving mass flow from the hot to the cool component was proposed by Hutchings et al. (1975), but the physics of such a situation if it really occurs would be hard to understand.

The radial velocities of AR Pav were interpreted by Thackeray and Hutchings (1974) as those of a single lined spectroscopic binary. Gas streams were also detected for this star, passing as one expects from the cool to the hot component. The star also appears to have eclipses, which agree in phase with what one expects from the radial velocity solutions.

The radial velocity variations of V1329 Cyg measured by Grygar et al. (1979) and by Iijima et al. (1981) were interpreted by both groups of authors in the single lined spectroscopic binary framework. Photometric minimum seems to occur at the phase expected for eclipses from the radial velocity curve, though it is not at all certain that classical eclipses are involved. The radial velocities of BF Cyg, RW Hya and R Aqr also show periodic variations, which could be orbital according to Boyarchuk (1969).

The situation is however not so clear for other symbiotic stars. Radial velocity variations are observed for Z And, but as shown by Boyarchuk (1968), the radial velocities instead of depending on an orbital phase, are correlated with photographic brightness. Orbital variations cannot be more than 5 km s^{-1}, and Boyarchuk supposing that the lines were formed around the secondary having a mass of only 1/9 of that of the primary, concluded that the inclination of the system could not be more than 10°. This is a somewhat improbable situation with a probability of only 1/66, and it appears that the only likely binary models of this star require emission line formation either between the components, or around the primary, generally taken as the cool star.

A similar problem exists for AG Dra according to Smith and Bopp (1981), who found no clear evidence for radial velocity phase dependence. These authors suggested that the red component had pulsations; one could indeed imagine that a combination of pulsations and orbital motion produces complex radial velocity variations. Pulsations have also been suggested by Smith (1980) to explain the radial velocities of EG And; it may however not be a classical symbiotic star. Pulsations were detected by Faraggiana and Hack (1971) for CH Cyg; a complex situation exists for it whose explanation in the framework of binary hypothesis is not clear, though these problems may be overcome by invoking gas streams and a wind to be discussed later.

A more serious problem may exist for RR Tel, if one uses the data compiled by Thackeray (1977). No evidence for periodic radial velocity changes was found. Though small systematic differences between different

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emission lines were seen, interpreted as due to blending with weak P Cygni absorption components, mean radial velocities for several ions were determined having standard errors between 1.9 and 0.5 km s^{-1}! It might be useful to re-examine the data. Formation of lines around a massive primary, combined with small pulsations having another period (periodic light variations occurred before outburts), might make it difficult to detect periodic variations. Thackeray himself suggested that some lines might be circumstellar.

To summarize, while the radial velocity variations of some symbiotic stars agree well with the binary conception, difficulties exist for several of the stars discussed. More studies of these stars and others not mentioned, are required.

(b) Accretion.

The various phenomena of accretion (Roche lobe overflow, bright spots, accretion disks, boundary layers, accretion columns, etc.) are basic to the physics of cataclysmic binaries, to which symbiotic stars are often related. As we shall see these phenomena are probably present, but all characteristics of symbiotic stars probably cannot be explained by them.

There is evidence in some cases that the red component is best not considered as filling its Roche lobe. Hutchings et al. (1975) found that the red component of AG Peg was 4 to 6 times smaller than the Roche lobe polar radius. Using the red star radius conditions of Keyes and Plavec (1980), the star would have to be at a distance of 2 kpc to fill the Roche lobe of Hutchings et al., and hence at a distance of 1 kpc from the galactic plane. AG Peg is however not a high velocity star. A similar situation may exist for Z And if the 680 day period is orbital. The size of the Roche lobe can be estimated to be of the order of 2×10^{13} cm, while the red star radius given by Altamore et al. is 9×10^{12} cm. It is not clear however whether the difference is significant. On the other hand Thackeray and Hutchings (1974) found that the red component of AR Pav could fill its Roche lobe, and the same applies to CI Cyg according to Stencel et al. (1981). In cases where the Roche lobe is not filled accretion could of course be from a wind.

Examination of emission line profiles clearly suggests the existence of an accretion disk for AR Pav. Thackeray (1959) considered that the emission lines could come from a thick rotating ring, but had difficulty explaining all observations. It might be interesting to re-examine them, taking account of possible bright spot eclipses by the red star and its wind.

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The emission line profiles of other symbiotic stars are less easily interpreted in this framework. For instance as pointed out by Altamore et al. (1981), the half intensity widths of the emission lines of Z And observed with IUE correspond to Doppler velocities of not more than 60 km s^{-1}. If formed in a disk such lines would unless an improbable geometry is assumed, have to be at at least $3x10^{12}$ cm from the central star. Even lines of highly ionized species such as NV, which might be expected to be formed near the disk center, could only be formed near the outer edge of a disk not much smaller than the Roche lobe. In that paper it was also found that the NIII] lines come from a region of low radiation density at at least $1x10^{12}$ cm from the hot component, while somewhat less rigorous reasoning led to a maximum line of sight thickness and suggested line formation in a region with a large extension compared with its thickness.

It may be noted that line formation in an outer "excretion" disk such as that which probably existed during the 1978 outburst of the unusual dwarf nova WZ Sge, might also be possible. Such disks with a smaller rotation velocity, would give rise to narrow lines. The nature and conditions for their existence are however badly known.

A preliminary examination of IUE spectra of AG Dra suggests emission line half intensity widths of the same order as those of Z And, and this also is the case for CI Cyg. The latter and perhaps both AG Dra and CI Cyg have eclipses, so it would be hard to explain line narrowness by orientation effects. The eclipses of CI Cyg moreover can be used to test for the region of narrow line formation. An eclipse was observed with IUE by Viotti et al. (1980) and by Stencel et al. (1981). Different lines are eclipsed to different extents, indicating formation in somewhat different regions. In particular NV appears hardly to be eclipsed, and this casts doubt on the occurrence of the most ionized regions close to the hot star, especially as the continuum eclipse appears to be 0.35 dex in the far UV (Baratta et al. at this meeting). This suggests that these unlike less ionized regions, occur rather around the eclipsing star than in an accretion disk. It should also be added that the eclipsed lines need not necessarily be formed in a disk; some could be partly formed on the side of the eclisping star facing its companion, and partly in gas streams and or parts of an eclipsing star wind deflected by the latter.

The presence of an accretion disk would also affect the continuous energy distribution of a symbiotic star. Webbink (1981) analysed the light curve of the 1975 eclipse of CI Cyg, and considering the effect of the emission lines was not large, concluded that one needed to assume the total eclipse of an accretion disk to explain the form of the light curve. A large mass accretion rate of at least $7x10^{-4}$ $M_{\odot}yr^{-1}$ is needed for Webbink's model; it should be noted however that CI Cyg was active at the time of eclipse, and that the situation may be quite different in quiescence. In any case the calculation should be done with new data at different wavelengths for different epochs.

The spectral energy distribution can be compared with disk models, which can also be used to predict the expected photoionization of gas in various regions. Kafatos (1981) considered the ionization of "nebular" gas by a disk plus a hot boundary layer, and was able to explain emission line fluxes. In addition Kenyon (1981) has attempted to fit observed energy distributions to disk plus boundary layer models, and obtained fits for all stars considered except BF Cyg. The accreting star according to him could be a main sequence star or a subdwarf. However it is not sure that the boundary layer temperatures of his models would be high enough to produce the states of highest ionization in all cases by photoionization. In particular his model gives a boundary layer temperature of $\lesssim$ 35000°K for Z And, not very different from the black body temperature of 43000°K found by Altamore et al. (1981). The flux of photons able to doubly ionize helium would be a factor of 10^3 too small to produce the observed 1640 A flux of Z And for the latter temperature; the temperature required in fact would be near 80000°K. The situation is probably even worse for the production of the ground state of NV. It must be noted however that if as reported by Viotti at this meeting, there was a very hot component to the continuum of Z And, this argument could not be used.

To conclude this section, accretion from disks almost certainly occurs in some cases at least; it is however not clear whether accretion disks are present all the time for all stars, particularly in the quiescent state in which Z And now is.

(c) Stellar winds from each component

Winds can occur from both components of a binary, and their properties are probably important for understanding symbiotic stars.

Winds from the hot stellar component seem to play a major role in some cases. Such a wind could be expected to have a velocity of the order of the stellar escape velocity, that is near 10^3 km s^{-1}. The broad P Cygni part of AG Peg line profiles mentioned by Keyes and Plavec (1980) probably comes from such a wind, especially as Hutchings et al. (1975) found from ground based data that gas was apparently leaving the hot star. The mass loss rate of 10^{-6} $M_\odot yr^{-1}$ found by Gregory et al. (1977) using radio observations is very large, and presumably associated with continuing activity since the outburst of AG Peg in the 19th century.

If this mass loss occurred from the hot star, and the distance of AG Peg is 0.5 kpc, one finds that the wind would have an optical depth of unity for Thomson scattering at about two solar radii. The photosphere defined as the level above which a photon in its random walk between scatterings would cross a free-free plus free-bound optical thickness of one would then be near a radius of 5×10^{10} cm at 2000 A. This is not far from the hot star radius given by Keyes and Plavec, which then would have a false photosphere formed by an optically thick wind.

The Wolf-Rayet features of RR Tel observed by Thackeray and Webster (1974) between 1951 and 1960 with a width of the order of 2000 km s^{-1} at some epochs, are also most easily interpreted as due to wind from the hot component. The P Cygni absorption component of RX Pup at velocity near 1000 km s^{-1} observed by Swings and Klutz (1976) may have a similar explanation.

The winds arising from the cool stellar component probably play a more fundamental role for many symbiotic stars. The compact "nebula" of R Aqr could be the result of mass loss from the cool star according to Michalitsianos et al. (1980). Such a wind would have a low velocity, and could be where the narrow emission lines seen in many stars are formed. Information about normal cool giant velocities is given by Reimers (1980), where one sees that velocities can be of the order of 10 km s^{-1}, much less than the stellar surface escape velocity. Using the Altamore et al. (1981) data, one finds that for the HeII 1640 A line to be formed in a wind, a mass loss rate of about $3\text{-}8\times10^{-7}$ $M_{\odot} yr^{-1}$ is required. Taking the Kudritzki and Reimers (1978) constant for the red giant mass loss formula, the expected mass loss rate of the cool star of Z And if it was single is $3\times10^{-8} M_{\odot} yr^{-1}$, when the star is supposed to have a mass of 3 $M_{\odot}$. In view of the uncertainties, this is surprisingly close. It should be noted that there is some doubt concerning the mass loss rate formula; while a conversation with Kwok at this meeting suggests that a mass loss rate below 10^{-7} $M_{\odot} yr^{-1}$ would be hard to detect in the radio region.

Thackeray (1977) suggested formation of the lines of RR Tel in an accelerating wind, with ionization increasing outwards. This is almost certainly the opposite situation to that of a classical nova in its decline after maximum. It is probably easiest to suppose formation of the non Wolf-Rayet lines in the cool star wind, even though the terminal velocity of the order of 100 km s^{-1} at least at certain times, is high for a normal red giant. In any case line profiles are perhaps more easily explained by a wind than by rotating disk.

Feast et al. (1977) related the presence of strong winds to the cool star being a Mira variable and the presence of dust. In such a case they suggested that accretion was from a Mira wind, while in other cases it was due to Roche lobe overflow. This division into two classes parallels the division of emission line stars including symbiotic ones by Allen and Glass (1974) into S (stellar) and D (dust) types, according to the nature of the infrared energy distribution. Z And belongs to the former, and RR Tel to the latter type. The study of Mira variables in D type symbiotic stars has been extended by Willson (1981). According to her the Mira variables that occur are fairly normal, though the period distribution is different perhaps because large mass loss rates for wind accretion are associated with long period Miras. From evolutionary considerations a critical orbital period was defined, which determined whether a binary will become an S or D type symbiotic star.

From the previous discussion it appears that cool star winds can also be important in S type cases like Z And. In addition in a very recent study with R.E. Stencel and R. Viotti (paper in preparation), it was found that the high excitation permitted far ultraviolet resonance lines in all symbiotic stars for which we have data, are red shifted with respect to the wavelength system defined by the intercombination lines. The former lines can be expected to be optically thick, and such a shift could be produced either by the presence of weak P Cygni absorption or by a radiative transfer effect, which occurs when photons are scattered many times in a slowly expanding medium. Both explanations suggest either line formation in a slow wind or at the base of the wind where expansion has begun, but not in a rotating disk.

Collisions between the winds from each component might be expected to play an important role in some cases. For instance it might using such concepts be possible to explain the observations of AG Peg in a physically more probable way than that of Hutchings et al. (1975). Wallerstein (1981) has described colliding wind calculations of Willson that can explain the peculiar changing profiles of V1016 Cyg and HM Sge. Such a picture does not necessarily contradict the existence of an outer nebular shell, which exists in the model of Nussbaumer and Schild (1981). These problems have also been considered by Kwok (1981).

(d) Enhanced outer layer heating of the cool component

The study of Z And by Altamore et al. (1981) as well as new additional arguments of mine given here for Z And and CI Cyg, suggest formation of high ionization ultraviolet lines far from the hot component of stars of this type, and can most easily be interpreted by formation around the cool component. It may be noted that emission lines of singly ionized metals also may be produced by photoionization in the atmosphere of the cool component, as for instance suggested by Boyarchuk (1967) for AG Peg.

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There may nevertheless be problems of explaining the most ionized states by photoionization, so line formation in a hot wind or in a hot region at the base of the wind, having a large extension compared with its thickness, is suggested.

However since the work of Linsky and Haisch (1979) it is known that single red giants resembling the cool components of most symbiotic stars, seem neither to possess hot outer layers, nor hot winds. Binaries nevertheless can have enhanced activity; in particular the RS Cvn stars which rotate faster than single stars of the same class. In the recent study with R.E. Stencel and R. Viotti already mentioned, we suggest that rotation could also be associated with enhanced heating of the outer layers of the cool components of some symbiotic stars. Normal red giants are expected to have rotational velocities of the order of several cm s^{-1}, while red components of symbiotic stars could be tidally spun up to velocities of several km s^{-1}. Details still need to be considered, including reasons why not many more stars are symbiotic.

The clearest test of such concepts would be to measure the electron temperatures of the regions where the states of highest ionization occur. Electron temperatures are notoriously more difficult to determine than electron densities; the most suitable method is perhaps that of Stickland et al. (1981) where fluxes of collisionally excited lines are compared with those of the next lower stage of ionization formed by recombination in the same region. The method is unfortunately not sensitive at high temperatures. An approximate attempt to measure the temperature of the NV region of Z And from the 1718/1240 A flux ratio gives a minimum electron temperature of 18000°K, which at least is not inconsistent with the model proposed here.

When the method was applied however to RR Tel by Penston et al. (1981), an electron temperature of only 15000°K was found, not much higher than that corresponding to the other line ratios formed in less ionized regions. RR Tel is thought however to have dust in its wind, and winds from D type symbiotic stars are presumably cool. The results presented by Mussbaumer at this meeting, suggesting possibly a high electron temperature for RR Tel indicates that such reasoning could be nevertheless too simplistic.

It may be noted that the "yellow" symbiotic stars defined by Glass and Webster (1973), whose cool components are less cool, including AG Dra, may have a somewhat different behaviour. Their cool components if single would according to the terminology of Dupree (1981) be perhaps "hybrid", having "warm" coronae with temperatures of at least 2×10^5°K. Excess heating might be less necessary for these stars. In any case the winds and outer layers of symbiotic stars in general are probably not very hot (i.e. do not have temperatures of more than a few times 10^5°K), as X-ray emission was not detected in many cases.

IV. CAUSES OF SYMBIOTIC ACTIVE PHASES

I shall only briefly touch on this subject. Nuclear burning in particular will be considered by other speakers.

Bath (1977) has proposed that accretion powers optically thick winds, accelerated by the radiation pressure associated with a luminosity close to and occasionally in excess of the Eddington limit. He considered that the visual brightness changes are due to mass loss rate changes affecting the radius to which the wind is optically thick, and hence the flux per unit area and the effective temperature of the photosphere. A major difficulty is that there is no evidence of such large luminosities of the hot component. The luminosity of that of Z And according to Altamore et al. (1981) is 7.7×10^{35} erg s^{-1} or 5×10^{-3} of the Eddington limit of a one solar mass star. To bring it up to the Eddington limit, one would have to suppose the star at 17 kpc or 3.6 kpc above the Galactic plane. The distance estimate of Altamore et al. is based on the uncertain luminosity of the cool component, but increasing the estimated distance to 17 kpc, would make this component bigger than the size of the orbit of the hot component, while one would expect it to be a high velocity star for which there is no evidence.

Using the results of Keyes and Plavec (1980), AG Peg would have to be at a distance of 8 kpc and 4 kpc above the Galactic plane for the hot component to be at the 1 $M_\odot$ Eddington limit. Similar problems arise as those for Z And. The situation is here however puzzling, because as we saw, there is probably an optically thick hot component wind, and it is not clear how it can be driven if AG Peg is far below the Eddington limit.

It should also be noted that according to a recent study of mine (Friedjung 1981), probable solutions for supercritical winds should satisfy a condition relating the radiative flux to that of kinetic energy. Classical novae which probably have such winds after outburst, approximatly satisfy the condition, but Z And does not.

Somewhat speculatively I would like to suggest that active phases of at least S type symbiotic stars are related to changes in the chromosphere, corona, and wind of the cool star. A warm wind might become a cool one of low velocity, and perhaps also a slight expansion of the chromosphere might enable Roche lobe overflow to take place. The accretion rate would increase, as accretion from a wind is very sensitive to its

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velocity, varying as the inverse fourth power of it. At the same time lines of high ionization species would tend to disappear in the spectrum. An accretion disk might form, or grow considerably if already present. AG Peg seems to require something more; perhaps nuclear burning of accreted gas by the hot component.

V. CONCLUSIONS

Symbiotic stars are probably binary, though it is hard to regorously disprove models of a cool central object surrounded by a hot envelope. The interpretation of the radial velocity measurements also poses problems for certain stars.

A number of different physical processes seem to play important roles in symbiotic stars. Accretion disks exist at least in some cases, but it is not clear whether they are always present in quiescence. Winds from both components, and particualrly from the cooler one, are important, while there is evidence that excess heating of the outer layers of the cool component occurs at least for some symbiotic stars.

The nature of outbursts was considered. Bath's model of optically thick winds driven by radiation pressure encounters difficulties. A new suggestion was made, connected with a change of the cool star's wind.

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