SIMILARITIES AND DIFFERENCES BETWEEN WOLF-RAYET WINDS AND SYMBIOTIC NOVAE

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Abstract. It has frequently been suggested that Wolf-Rayet stars are present in symbiotic systems, in particular in symbiotic novae. We dismiss that suggestion as far as it concerns Wolf-Rayet of Population I. There may, however, be similarities to WR stars found as central stars of planetary nebulae. – When treating wind phenomena in our binary configurations, there are common properties which justify that for certain investigations Wolf-Rayet and symbiotic systems are considered together.

Key words: star: symbiotic novae – Wolf Rayet – colliding winds – planetary nebulae

1. Introduction

Are all of them binaries? In the case of Wolf-Rayet stars the debate has lost its vigour when it was realized that the WR evolution needs no companion, but can occur during the evolution of an isolated massive star. For symbiotic systems the question of binarity was still open at the time of the first IAU Colloquium on symbiotic stars in 1981. Today there is agreement that the symbiotic phenomenon is intrinsically linked to binarity. Stellar winds can form qualitatively completely different configurations when occuring on single stars or in a binary system. I shall concentrate on double star systems.

2. WR stars in symbiotic systems?

Let me introduce you very briefly to symbiotic systems. In symbiotics both stars are in a late stage of stellar evolution. One is a red giant with heavy mass loss. The other may resemble the central star of a planetary nebula, with a radiation field that ionizes a considerable fraction of the nebular material within the binary, typical temperatures are $T_* = 120\,000 \pm 80\,000$ K. Known binary periods range from one year to several dozen years. The total masses of symbiotic binaries do probably not exceed 3 to 4 $M_\odot$. Thus, we deal with low mass systems.

Symbiotic novae differ from ordinary symbiotic stars in that we have witnessed only one single, long-lasting outburst. It looks like a very drawn-out classical nova. The current model advocates that for several thousand years the white dwarf has been accreting material from the wind of the red giant. When reaching a critical mass, a thermonuclear runaway sets in. The outburst can be accompanied by mass loss, or simply by the expansion and subsequent contraction of the accreted shell. For further reading see

K. A. van der Hucht and P. M. Williams (eds.), Wolf-Rayet Stars: Binaries, Colliding Winds, Evolution, 309–317.

Mikolajewska & Kenyon (1992), or Mürset & Nussbaumer (1994), or Shaviv (these proceedings) for novae in general. – Symbiotic novae were often associated with WR stars, let me list some of the candidates. AG Peg is the oldest symbiotic nova, its outburst began between 1840 and 1850. Boyarchuk (1967) investigated spectrograms containing many emission lines. He separated them into three groups: nebular lines, lines associated with the M-giant of the system, and a set of broad (≈ 6Å) He II, C IV, N IV, O III lines which he attributed to a WN6 star, with the qualification: 'the widths of these lines is considerably smaller than for normal WR stars, corresponding roughly to the line widths in the spectra of planetary-nebula nuclei which are of WR type'. For HM Sagittae, whose outburst began in 1975, Ciatti *et al.* (1978) pleaded for a WN6 star. For V1329 (HBV 475), whose outburst became prominent in 1964, Crampton *et al.* (1970) suggested that the spectrum looked like that of a WN5 star surrounded by a diffuse nebula. That was supported by Andrillat & Houziaux (1976). For RR Tel Thackeray & Webster (1974) speculate that in 1958–60 they were seeing a WR star with an effective temperature $T > 10^5$ K.

The WR evidence rests on the the few broad emission features mentioned above. But that does not suffice to infer a WR star, in particular as these features have a tendency to disappear after a few years. Today we associate the broad emission lines with the nova-like outburst of the hot component. Vogel & Nussbaumer (1994) looked at the *IUE* spectra taken of AG Peg from 1978 to 1993. They find mass losses that diminish from $\sim 3 \cdot 10^{-7}$ $M_\odot$/yr in 1978 to $\sim 7 \cdot 10^{-8}$ $M_\odot$/yr in 1993. The wind has a terminal velocity of $\sim$ 900 km/s. Assuming that the WR candidate is actually a hot subdwarf, Mürset & Nussbaumer (1994) derive from the mass-luminosity relation $M_{\rm hot} = 0.54\ M_\odot$. From the velocity curve Cowley & Stencel (1973) derived $M_{\rm hot} < 1\ M_\odot$. This is far from a Population I type WR star, but does not exclude planetary nebula type Wolf Rayets.

Principal characteristics of WR stars are their very low H/He ratio and strong winds. Alas, we have at present no spectra of the hot component of symbiotic stars which allow a determination of the H/He-ratio. On the other hand, there is at least in the symbiotic nova PU Vul an indication of C/N/O abundances in the wind of the hot star which is not solar but rather points to a nova event (Vogel & Nussbaumer 1992). A main obstacle against observational clarification is the presence of the nebular spectrum. It drowns the emission from the hot wind. We would have to carefully disentangle the feet from the main body of the line profile. That was done for the symbiotic nova AG Peg by Vogel & Nussbaumer (1994). – We can therefore exclude the presence of Population I type WR stars in symbiotic systems, but we cannot exclude planetary nebula type WRs, although a nova event gives a more satisfactory description.

3. The concept and observation of colliding winds

Let us briefly recall how the idea about stellar winds from WR stars formed. In the 1968 JILA-Symposium on WR stars there was still ample discussion, whether the observed broad emission lines were due to turbulence or radial mass motion. In the same meeting the first rocket spectra with unambiguous P-Cygni profiles were presented. They came from γ Velorum, and showed emission and absorption components of C IV, Si IV, C II. They corresponded to velocities of about 1 500 km/s (Stecher 1968). For driving these winds radiation pressure was mentioned. The UV observations inspired the pioneering work of Lucy & Solomon (1970) on mass loss by hot stars. *IUE* definitely established that heavy mass loss is a general feature of WR stars, *e.g.,* Barlow *et al.* (1981).

I found the earliest treatment of colliding winds in WR systems in Prilutskii & Usov (1976). They were looking for objects that might be candidates for the X-ray sources identified up to then. They presented three configurations that would produce shock waves in double star systems, and they argued that the WR stars γ Vel and V444 Cyg were good candidates for being X-ray sources. They gave the location of the shock as the surface were the dynamic pressure of the two winds is equal: $\rho_1(r_1)v_1^2 = \rho_2(r_2)v_2^2$. From the geometric configuration and the mass losses, the luminosity of the colliding shock can be calculated on the assumption that the kinetic energy is transformed into radiative energy. Shore & Brown (1988) revived the model of two colliding winds for their discussion of V444 Cyg, they based their considerations on *IUE* observations.

For symbiotic systems Girard & Willson (1987) tried to explain X-ray observations as well as broad, structured profiles of emission lines with colliding winds. They also calculated the position of the shock front on the basis of equality of wind momenta. They speculated that the radial winds, deviated along the shock front, would provide the flow patterns that could explain the observed line profiles. The concept of colliding winds was put on safe grounds when Nussbaumer *et al.* (1988) showed that the nebular material in symbiotics is primarily due to mass loss of the cool giant, and that also the hot star possesses a wind of its own (Nussbaumer & Vogel 1990).

Mass losses of symbiotic novae, estimated from radio observations, range from 10^{-8} to 10^{-5} $M_\odot$/yr (Seaquist *et al.* 1993). For AG Peg Kenny *et al.* (1991) estimate from radio observations a mass loss of the red giant of $M_{cool} \approx 3 \cdot 10^{-7}$ $M_\odot$/yr when assuming a terminal velocity of $v_{cool}^{\infty} = 10$ km/s. I have mentioned before that the mass loss of the hot component in AG Peg diminished from $\sim 3 \cdot 10^{-7}$ $M_\odot$/yr in 1978 to $\sim 7 \cdot 10^{-8}$ $M_\odot$/yr in 1993, with the terminal velocity remaining at ~ 900 km/s. We thus find a highly asymmetric situation. Although the mass losses of the two stars are

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approximately equal, the mechanical power resides mainly in the hot wind, whereas the nebular emission originates mainly from material ejected by the cool giant.

For WR stars Barlow *et al.* (1981) find typical mass losses of a few times 10^{-5} $M_\odot$/yr. In their study of V444 Cyg (WN5+O6) Shore & Brown (1988) work with mass losses of $\sim 1 \cdot 10^{-5}$ $M_\odot$/yr for the WR star and $\sim 2 \cdot 10^{-6}$ $M_\odot$/yr for the O star, with comparable terminal velocities of $\sim$ 2000 km/s for both. Thus, mass loss and kinetic momentum in the winds of the two components of WR-binaries will often be such that one of them dominates, but not as extremely as in the symbiotic system. But for both systems we expect the wind interaction to modify the circumstellar environment quite dramatically.

Binary motion has additional effects. Binary periods in symbiotics are between one and several dozens of years, for WR stars van der Hucht *et al.* (1981) give periods from 1.6 up to 79 days. Typical binary separations in symbiotics are a few times 10^{14} cm which implies a crossing time of a few months. In WR systems separations are a few times 10^{12} cm and the crossing time for the winds is a few hours. Thus, in both systems the crossing time is typically one or a few tenths of the binary period. The wind collision problem can therefore be split. Between the two stars it can to a reasonable approximation be treated as if the two stars were at rest, in the wider confines that approximation breaks down. Centrifugal and Coriolis forces need be included, and additional effects of wind interactions play a part. In the WR system the final velocities and the momenta of the two winds are not much different from each other, whereas in symbiotics the crossing time between the two stars is defined by the fast wind of the hot component. The wind of the cool star is much slower and has therefore a larger inertia against following the binary motion.

4. Wind accretion

From consideration of angular momenta accretion in symbiotics and WR systems is likely to occur via wind accretion and not via accretion disks. The exceptions in symbiotics may be CH Cyg, CI Cyg, and AR Pav. Although Baade *et al.* (1990) present observations of γ Vel that might be interpreted as coming from a disk structure, it is rather unlikely that an accretion disk forms around an O-star.

If in symbiotics a white dwarf accretes from the wind of the red giant, this can lead to a second red giant or a nova event. Or, if accretion heaves the star towards the Chandrasekhar limit, a supernova could result. These possibilities are discussed by Shore, Livio, and van den Heuvel in the 1992 Saas Fee lectures (Nussbaumer & Orr 1993). For AG Peg some numbers are available. Now, in 1994, the luminosity is nearly back to pre-outburst.

During the 150 years of activity it has radiated a total of $\sim 3 \cdot 10^{46}$ erg. This corresponds to a H→He conversion of $2.5 \cdot 10^{-6}$ $M_\odot$. This mass must have been accreted beforehand from the wind of the red giant. If the mass loss of 1978 to 1993 was typical for the whole outburst (Vogel & Nussbaumer 1994) and was earlier accreted, the total previous accretion was $\sim 10^{-5}$ $M_\odot$.

Whether symbiotics become supernovae is still debated. Munari & Renzini (1992) think that they do. But, symbiotics are low mass binaries. Mürset & Nussbaumer (1993) give for the hot star $M_{\rm core} \leq 1.1$ $M_\odot$. With red giant masses of $M_{\rm RG} \leq 2$ $M_\odot$, and a wind accretion efficiency of $\sim 1\%$, there is simply not enough material to reach the Chandrasekhar limit, which coincides nearly with the critical mass. However, if there are other mechanisms that help to produce type I supernovae from white dwarfs with masses < 1 $M_\odot$, then symbiotics become viable candidates.

Large accretion disks are likely when accretion occurs via Roche lobe overflow, thus in systems where the radius of the donor measures a substantial fraction of the binary separation. Neither symbiotics nor WR stars are as a rule in such configurations. – Although the formation of large accretion disks is unlikely in relatively wide binary systems, smallish and probably unstable accretion disks may form close to the accreting star, they appear in hydrodynamic calculations as transient events.

5. Hydrodynamic calculations

Colliding winds and wind accretion can be treated as hydrodynamic problems. Stevens *et al.* (1992) did a first full hydrodynamic calculation explicitly for WR stars. For symbiotics that was done by Nussbaumer & Walder (1993). In a hydrodynamic treatment the conversion of the initial kinetic energy into thermal energy, is calculated locally by a set of coupled differential equations, for example the Euler equations. In their usual form they conserve mass, energy (kinetic and thermal), and momenta. In a first step towards radiation-hydrodynamics radiative processes such as cooling or heating by radiation are added, as well as ionization processes. The collision region is no longer an infinitesimally thin plane, but assumes a life of its own.

But, the collision front is more than a producer of X-rays. Its internal dynamics modifies the environment. In addition, instabilities become a determining feature. They have either (a) a physical explanation, or (b) they are due to numerical artifacts. There are a number of ways that lead to real instabilities, as an example I mention the cooling instability which is triggered in the following way: The cooling function is fairly constant over the $3 \cdot 10^6 - 10^8$ K range. These temperatures are easily reached in a collision region. A drop below $3 \cdot 10^6$ K increases the cooling efficiency substantially. Cooling then may proceed on a much shorter time-scale then the relevant hydrodynamical processes, thus destroying the equilibria of pressure and

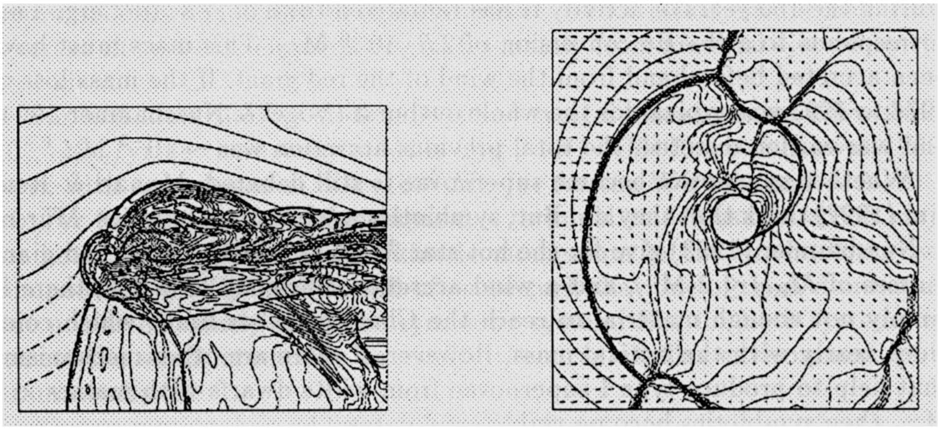

Fig. 1. Two-dimensional wind accretion (Zarinelli *et al.* in preparation). Left: density contours; right: velocity vectors from the innermost part, together with density contours.

momenta (see Walder & Folini, these proceedings). That will affect the dynamics of the whole environment.

Numerical effects can not only produce instabilities, they also can do the opposite and damp or even prevent them. Thus, a smooth solution appears, where an instability should occur. All these effects render the numerical treatment of shocked regions a delicate matter; see also Walder (these proceedings).

Accretion is of great interest in symbiotic novae. The classical treatment of Bondi & Hoyle (1944) has been reassessed during the last few years by many groups including Arnett, Fryxell, Ishii, Livio, Matsuda, Soker, Taam (those not mentioned may forgive me). The most recent work is by Ruffert (1994), who presents a 3-D study. A qualitative difference against 2-dimensional calculations is the resulting stability. The flip-flop instability seen in 2-D calculations does not appear to the same extent in three-dimensional flows, except when the accretor becomes small. (For a discussion on flip-flop see also Livio, 1992.) This is a crucial point. Models often work with oversize accretors. Realistically small dimensions – the accretor often is a white dwarf – are still outside the capabilities of our computers. We see qualitative changes when the size is varied. The snapshot given in Fig. 1 gives an impression of the complicated pattern that arises when hydrodynamic calculations are pushed to high spatial resolution. The illustration is from a model, where the accretion radius, r_a, has a ratio of 25 compared to the radius of the accretor. For r_a we use the definition $r_a = 2GM/v^2$, where M is the mass of the accretor and v the velocity at which the accretor moves in the general accreting medium. For an O-type star accreting from a WR, with $M = 30\ \mathrm{M}_\odot$, $R = 10\ \mathrm{R}_\odot$ and $v = 2000$ km/s, r_a is of about the same size as the accretor. But for the accreting white dwarf in a symbiotic system with $M = 0.5\ M_\odot$, $R = 0.1\ R_\odot$ and $v = 20$ km/s, we find $r_a = 7 \cdot 10^{12}$ cm and $r_a/R \approx 1\,000$. Although it is easier to give a realistic treatment to a WR+O star system than to a symbiotic binary, you would immediately run into a new set of problems due to the radiation pressure.

Particle hydrodynamics is a qualitatively different approach to hydrodynamics. The gas flow is simulated by test particles. Examples are the studies of wind accretion in binaries by Theuns & Jorissen (1993) or Boffin & Anzer (1994). The concept of temperature is foreign to this method and has to be introduced artificially. A thermal energy has to be assigned to each test particle. The number of test particles is limited by economic considerations. Shocks also have to be introduced artificially. The great advantage of the method is that by replacing the real gas with its huge number of particles by a relatively small number of test particles the computational work is much reduced. Therefore the method is fast and, with a given effort, more complicated cases can be treated than with proper hydrodynamics. Theuns & Jorissen (1993) find that 3-D wind accretion is quite different from the 2-D case. They find, in particular, a spiral arm which introduces asymmetry. That asymmetry helps the accretion of angular momentum. These studies are certainly of high interest, but they need confirmation by full hydrodynamic calculations.

Analytical investigations should not be neglected. They help to understand basic properties (*e.g.,* Usov, these proceedings) and instability phenomena (*e.g.,* Dgani *et al.* 1993 and references therein).

Let me add a few comments about some of the current problems. The difference between 2-D and 3-D methods is important. There are now the 3-D wind accretion calculations of Ruffert (1994), and the smoothed particle hydrodynamics by Theuns & Jorissen (1993). They strongly suggest qualitative differences between 2-D and 3-D cases; reality is three-dimensional. This is also valid for wind collision calculations, where Walder (these proceedings) gives examples. – Calculations also show that in accretion qualitatively different phenomena appear when the size of the accretor changes. Thus, the treatment of wind accretion as well as wind collision demand calculations with high spatial resolution to treat instabilities. This strongly increases the requirement on computer time and memory, and on the sophistication of the computational methods. We may still have to wait some time before valid hydrodynamic 3-D results appear. But, not only numerics, also physics need a big push. We all know that about the outstanding problem of viscosity. Yet, also the full step to radiation hydrodynamics still needs to be done. The accretion models mentioned do not include cooling by radiation, and for the colliding wind programs the cooling functions are based on the thermodynamic equilibrium approach. That may not be valid in the shock fronts with their steep temperature and density gradients, nor in the thin-shell instability regions.

Hydrodynamic problems of wind interaction and accretion in double star systems are still largely unsolved. The validity – when matched against astrophysical reality – of most model calculations is still questionable. Because of the similarities I mentioned, hydrodynamic studies for WR stars and symbiotic systems can profit from each other. It would also be highly desirable that independent codes are tested on identical physical problems.

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DISCUSSION:

Niemela: Central stars of PN which show WR spectra are almost always WC type, but there is one PN (N66) in the LMC whose central star has become WN and brightened (Pena et al. 1994, ApJL in press). This could be a symbiotic nova in the LMC.

Nussbaumer: At a first glance, spectra of young compact planetary nebulae and those of symbiotic stars can easily be mistaken for each other. This is one of the reasons why symbiotics have been suggested to be precursors of planetary nebulae. But here the opposite seems to happen. We could suspect here the scenario where a planetary nebula contains a binary: the central star of the planetary nebula and a mass-lossing star. If the central star has been refuelled by hydrogen-rich matter we might see now the outburst of a symbiotic nova.

Perinotto: You have shown huge changes of the NV 1240Å line profile in AG Peg in few years implying the sudden appearance of strong nebular components and important changes in the mass loss rate of the star, and you have expressed the idea that in planetary nebulae the situation might be quite different. I wish to comment that we are looking at the constancy of stellar winds in central stars of planetary nebulae (CSPN), by examining high resolution IUE spectra of about 20 CSPN, all known to have winds, and with a going on project at the 200" Palomar telescope. The UV data base consists of 2-4 well exposed spectra per object, at time intervals of some months to a few years. No variations have been seen in the nebular components, whereas only few of the observed stars did show moderate changes in the stellar line profiles components. On the other hand optical data indicate changes in some emission lines, particularly in CSPN of WR type, at very short timescales. But essentially we did not detect major variations in the important wind lines of the type you have reported to occur in symbiotic stars.

Schulte-Ladbeck: In your introduction you said that the hot star photoionizes the wind from the cool star. Does the shock manifest itself in the line spectrum, and if yes, can you look for instabilities by investigating the variability of the lines due to the shock?

Nussbaumer: The shock can indeed influence the line profiles, examples are given in Nussbaumer and Walder: 1993, A&A, 278, 209. But the examples we gave come from the low temperature ($T \approx 10000K$) flow along the shock. The shocked high temperature region has temperatures well above 10^6K. The emission of these regions would be observable in the 100-400Å range, where it will complete with the continuum emission from the hot star. The observational search for instabilities is very important as it will provide observational constraints to theoretical work. To do this systematically the theoreticians have to come up with estimates of the time-dependent emission spectra of their shocked regions.