WIND ACCRETION AND INTERACTION IN LONG PERIOD BINARY SYSTEMS

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ABSTRACT. Recent observations of the class of objects called symbiotic nova are reviewed. They are suggested to be widely-separated long-period binary systems undergoing mass exchange by wind accretion. Their radio, infrared, optical and X-ray properties are explained by a model of interacting winds.

1. INTRODUCTION

The subject of the evolution of close binary systems was reviewed by Paczynski (1980) in an invited discourse at the XVII I.A.U. General Assembly in Montreal six years ago. Depending on the extent of interaction, Paczyński classified interacting binaries into 4 groups: 1. detached; 2. semi-detached; 3. contact; or 4. common envelope systems. He further divides close binaries into evolutionary classes A, B, or C based on when a semi-detached system develops during the evolution. For example, for a binary system consisting of initial masses 5 and 2.5 $M_{\odot}$, a semi-detached system will develop before the exhaustion of hydrogen in the primary if the orbital period is less than 1.5 days (Class A). If the orbital period is between 1.5 days and 3 months then a semi-detached system will develop after H exhaustion but before the ignition of He and the system is classified as Class B. Similarly, a Class C system develops Roche Lobe mass transfer only after He ignition and the corresponding orbital period would be between 3 months and 12 years in this example.

It would be interesting to speculate whether any interacting binary system is possible if their initial orbital period is longer than that of a Class C binary. There is recent observational evidence that such systems indeed exist and this will be the subject of the present review.

1.1 Very-long period interacting binaries

It has become widely accepted now that advanced asymptotic-giant-branch (AGB) stars develop very strong stellar winds with mass loss rates of $\sim 10^{-5}$ $M_{\odot}$/yr (cf. Kwok 1980). If the AGB star is in a binary system with

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a companion which has strong surface gravity, e.g. a white dwarf, then it is possible that a significant amount of mass in the stellar wind can be captured by the companion. The accumulation of accreted wind material may eventually reactivate H shell burning in the degenerate dwarf and cause an outburst (Paczyński and Rudak 1980).

A number of such nova-like eruptions have been observed in the recent past and further observations reveal that the cool component in the system is very much different from that of a classical nova. Their optical history is also significantly distinct from that of a nova. These objects have been given various names in the literature such as slow novae, symbiotic novae, or eruptive symbiotics and their nature is still in controversy. In this review, I shall summarize the evidence to show that these objects are made up of an AGB star and a white dwarf and the interaction of their respective stellar winds is responsible for many of their unique observed properties.

1.2 Defining characteristics of symbiotic novae

In the absence of a universally accepted definition of a symbiotic nova, the following criteria will be adopted as a working definition:

1. The presence of high excitation emission lines (e.g. HeII) to indicate the existence of a hot star. This follows the definition for symbiotic stars by Allen (1979, 1984).
2. Molecular absorption bands such as CO, H_2O and TiO. These features are commonly seen in the spectra of late AGB stars.
3. Nova-like optical outbursts with an increase in V of several magnitudes.
4. Rich emission line spectrum in the visible and ultraviolet.

These requirements demand the presence of 3 components in the system: a hot star, a cool giant and an extensive circumstellar nebula. The nebula, from which the hot star accretes material, is presumably ejected from the cool component. There are 3 symbiotic novae in recent history: RR Tel in 1944, V1016 Cyg in 1964 and HM Sge in 1975.

2. HM SAGITTAE AS AN EXAMPLE OF A SYMBIOTIC NOVA

HM Sge was discovered in 1975 when its visible magnitude increased from 16^m to 11^m in 5 months. It was found to have a rich emission line spectrum including some high excitation lines (Stover and Sivertsen 1977). It also has a large infrared excess with the 9.7 μm silicate dust feature, suggesting the presence of a mass-losing AGB star. This is supported by the observations of molecular absorption features (Puetter *et. al.* 1978) and the Mira-like infrared variability (Ipatov, Taranova and Yudin 1985). Wolf-Rayet features of velocities ~2000 km/s are observed (Wallerstein 1978; Allen 1980; Swings and Andrillat 1981) which could be attributed to a fast stellar wind from the degenerate component. The presence of a dense and extended nebula is evident from the strong observed radio continuum emission (Kwok, Bignell and Purton, 1984). Its radio light curves (Fig. 1) resemble the optically thick phase of classical nova except that the time scale of this phase in HM Sge is of the order of years rather than months.

The most significant clue to the nature of HM Sge is Wallerstein's (1978) high-resolution observations which show that the emission lines of HM Sge have a large disparity in widths. He found that while Hα and HeI have broad wings indicative of expansion velocities of 1700 km/s, [OI] and [SIII] show velocities of 75 km/s and [NII] is very narrow with a velocity of 20 km/s. Wallerstein associates the narrow lines with the cool star and the [OI] and [SIII] with an expanding shell.

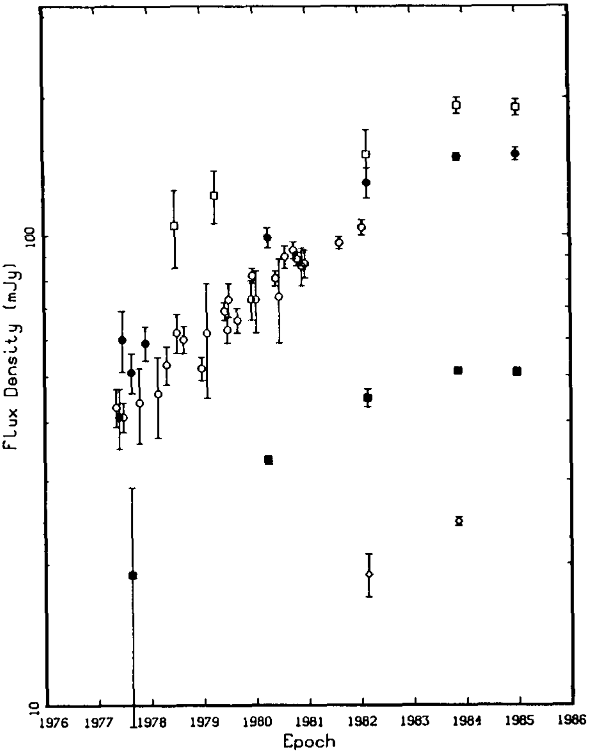

Fig. 1 Radio light curves of HM Sge
The different symbols represent
frequencies of 1.4, 5, 10.6, 15 and 23 GHz

3. THE INTERACTING WINDS MODEL

Wallerstein's observations led to the proposal of the interacting stellar winds model for HM Sge which the permitted lines (Hα and HeI) are suggested to arise from a high speed wind from the hot star and low critical-density lines ([NII]) are emitted from the wind of the M giant. If the hot-star wind began at the time of the outburst, then the interaction of this wind with the pre-existing M-giant wind will lead to the formation of a high-density shell from which the intermediate-critical-density lines ([OI] and [SIII]) are emitted (Kwok and Purton, 1979). Mass of the shell will increase with time as more of the M-giant wind material is swept up by the hot-star wind. A schematic diagram of the interacting winds model is shown in Fig. 2.

3.1 The dynamical equations

Assuming that the interaction between two winds is adiabatic and most of the shell is made up of swept-up mass then the conservation of mass, momentum and energy give the following three equations:

$$dM_s/dt = 4\pi R_s^2 \rho(r) (dR_s/dt - V) \qquad (1)$$

$$M_s\, d^2R_s/dt^2 + dM_s/dt\ (\ dR_s/dt - V\ ) = 4\pi R_s^2 P \qquad (2)$$

$$\frac{d}{dt}\,(2\pi R_s^2 P) = \frac{1}{2}\,\dot{m}v^2 - 4\pi R_s^2\, dR_s/dt \qquad (3)$$

where M_S and R_S are the mass and velocity of the shell, V and $\rho(r)$ are the velocity and density of the M-giant wind, $\dot{m}$ and v are the mass loss rate and velocity of the hot-star wind, and P is the pressure in the shocked region which is responsible for pushing the shell. If we assume a steady mass loss from the hot star ($\frac{1}{2}\dot{m}v^2$=constant) then equations (1)-(3) can be solved by similarity analysis yielding the following solutions:

$$R_s = V_s t \qquad (4)$$

$$M_s = \dot{M}\ (V_s/V - 1)t \qquad (5)$$

$$P = \frac{\frac{1}{2}\ \dot{m}\ v^3}{6\ \pi\ V_s^3} \qquad (6)$$

where V_s is given by

$$(\dot{M}/V)V_s^3 - 2\dot{M}V_s^2 + \dot{M}VV_s = \frac{1}{3}\ \dot{m}v^2 \qquad (7)$$

Assuming that V_S~100 km/s, v~2000 km/s and applying the jump conditions for a strong adiabatic shock, one finds that the inner shock is located at ~0.34 R_S, or approximately 96% of the volume inside R_S is shocked. Using the ideal gas law and assuming that the shocked region is uniform in density we

$$T = \frac{\mu\ m_H\ v^2 \epsilon}{9\ k} \qquad (8)$$

where μ (~0.6) is the mean atomic weight, k is Boltzmann constant, and ϵ is the filling factor. With the above parameters the shocked region is found to have a temperature of ~10^7K (Kwok and Leahy 1984).

X-ray emission is expected at such high temperatures and HM Sge is indeed found to be an X-ray source by the *Einstein Satellite* (Allen 1981). The X-ray emission was analyzed by Willson *et. al.* (1984) and Kwok and Leahy (1984). Willson *et. al.*

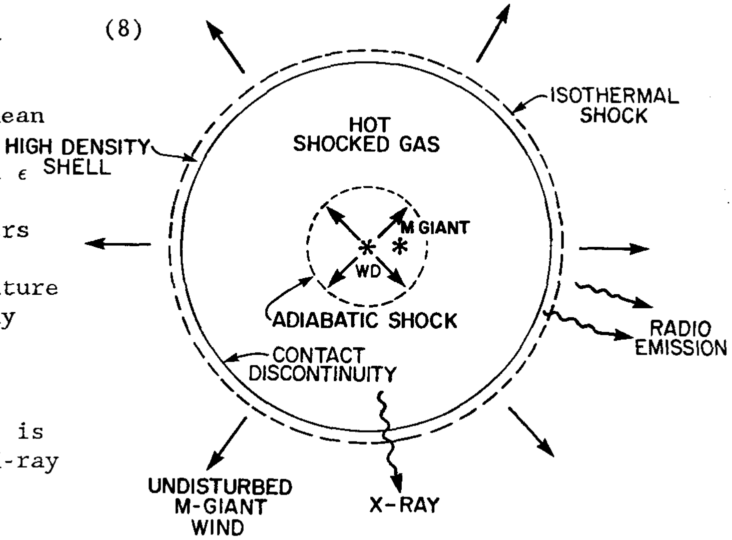

Fig. 2 Schematic diagram of the interacting winds model

suggest that the X-ray emission originates from the head-on collision region of the two winds whereas Kwok and Leahy find that the X-ray flux to be consistent with the expected emission from the much larger shocked region and derived a hot-star mass loss rate of $\dot{m}$~10^{-7} $M_\odot$/yr.

3.2 Observational tests of the Interacting Winds Model

The most obvious test of the predicted wind-shell structure of HM Sge is by direct imaging. Very high (~0.06 arc sec) resolution radio observations (Kwok, Bignell and Purton 1984) show a diffuse halo surrounding a central core of 0".15 in size in qualitative agreement with the model prediction. A more quantitative test would be to fit the multi-frequency radio light curves of Fig. 1 since measurements at different frequencies probe into different depths of the source and the optical depths are evolving with time. Using Wallerstein's (1978) velocities as input parameters Purton, Kwok and Feldman (1983) were able to obtain reasonable fits to the light curves with the interacting winds model.

Further confirmation of the model came from the recent high-resolution optical spectroscopic observations of Stauffer (1985). He finds that the [OIII] line of HM Sge to have a double-peaked profile which can be identified as the shell expanding at 41 km/s. A narrow (10 km/s) component is also observed in [NII] which probably originates from the red-giant wind. These observations are also in agreement with the suggestion in §3 that lines with lower critical densities show stronger narrow components.

4. DISTANCE AND LUMINOSITY

The distance and luminosity of HM Sge is still in controversy (cf Solf 1984). From the Balmer decrement, the extinction coefficient E_{B-V} is estimated to be ~0.4 (Stauffer 1985 and references therein). This suggests a distance of ~1 kpc in the direction of HM Sge. Since the presence of a 300^d Mira in the system demands a minimum luminosity of at least $6x10^3$ $L_\odot$, a minimum distance can be derived if the total emitted flux is known. Figure 3 shows the energy distribution of HM Sge. If we are not missing significant amount of flux (e.g. in the far ultraviolet) then the total observed flux is $9.6x10^{-8}$ erg cm^{-2} s^{-1} which implies a luminosity of $3.1x10^3$ $(D/kpc)^2$ L_o or a distance of >1.4 kpc. Such luminosity considerations are however severely constrained by the observed angular size and expansion velocity of the shell which require that the following expression be satisfied:

$$\theta = 0''.14 \ (V_s/42 \ km/s) \ (D/kpc)^{-1} \ (t/8 \ yr) \qquad (9)$$

where t is the time after outburst. Comparison with the observed angular size argues for a distance smaller than 1 kpc. At the present time we may wish to consider a distance of 1 kpc as a compromise.

5. FURTHER ISSUES TO CONSIDER

The interacting winds model discussed above makes use of the simplifying assumptions of spherical symmetry and steady state. There are, however, observational indications that a more complex model may be necessary. Wallerstein *et. al.* (1984) have found that many line profiles are asymmetrical and spectral dependence on position angle has been noted by Solf (1984). Such asymmetries may be due to non-isotropic ejections (Solf 1984) or orbital motion of the binary system (Wallerstein *et. al.* 1984).

Evidences also exist to question the steady-state assumption for the winds. The Wolf-Rayet feature attributed to the hot-star wind is found to have disappeared after 1980 (Feibelman 1982; Stauffer 1985) and this may imply that the wind has been weakening with time and ceased completely in 1980. This will cause the shell to decelerate and such deceleration should be detectable by continued monitoring of the radio light curves as well as by observing the profile changes of the emission lines.

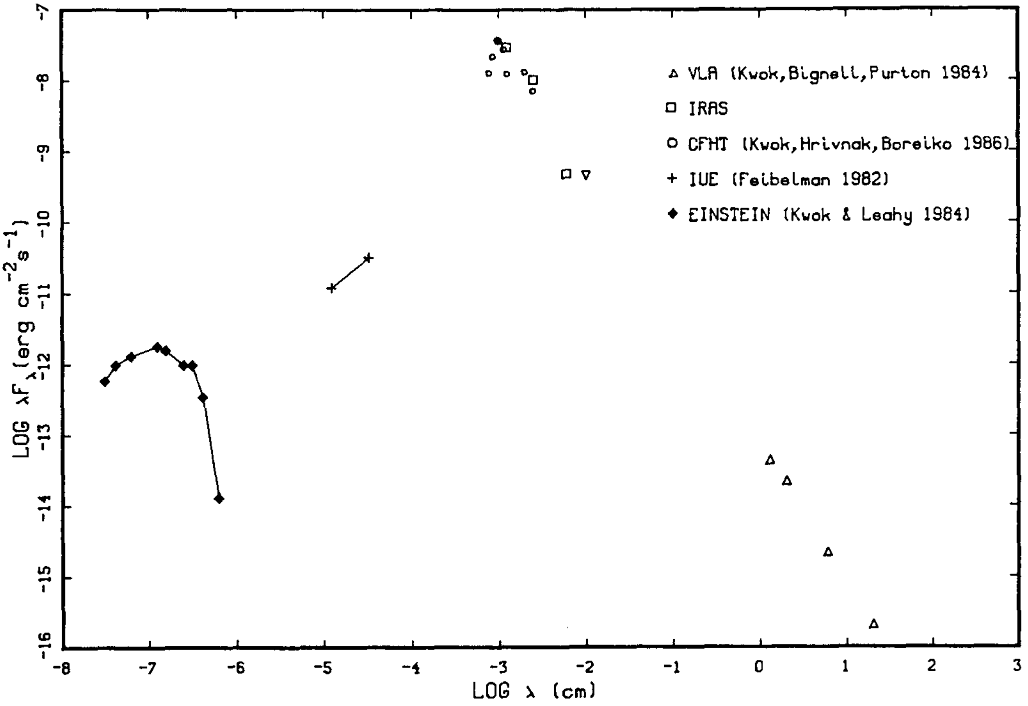

Fig. 3 Energy Distribution of HM Sge

6. CONCLUSIONS

Recent observations of symbiotic novae have shown that interaction between widely separated binary components is possible if one component is a late-type Mira Variable with a stellar wind and the other is a compact object with a strong gravitational field. The compact component can be re-ignited by accreting wind material of the M giant, leading to an optical outburst and a nova-like ejection. Strong shocks generated by the interaction of the winds of the two stars can produce activities throughout the electromagnetic spectrum from the radio to X-ray as illustrated by the remarkable object HM Sge.

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