Recent Activity in Two Symbiotic Stars

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Abstract

Two mechanisms, accretion events and thermonuclear runaways, have been proposed to account for the eruptions of symbiotic binaries. Recent observations of CH Cygni and RS Ophiuchi demonstrate the difficulties in applying either model to the data.

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1. Introduction

Symbiotic stars are a small class of variables whose spectra display features commonly associated with red giant stars and planetary nebulae (Allen 1984). These objects have been studied extensively since the early 1930's (cf. Payne-Gaposchkin 1957), and are commonly accepted as long-period (P $\sim$ 1-100 yr) interacting binary stars.

My review concentrates on recent eruptive activity in two symbiotic stars. This topic is especially appropriate for the 75th anniversary of the AAVSO, because amateur light curves are basic to our understanding of outbursts in all symbiotic systems. The combination of detailed light curves and careful spectroscopic observations has provided impetus for two basic outburst scenarios: (i) thermonuclear runaways and (ii) accretion events. Each model can explain the eruptive behavior of selected symbiotic stars, and the two systems which highlight this review illustrate the complexities of applying either model to a comprehensive set of data.

2. Eruption Mechanisms

Before discussing recent observations of CH Cygni and RS Ophiuchi, it is necessary to outline the basic properties of each outburst mechanism. Thermonuclear runaways involve accretion of hydrogen-rich material onto a fairly normal white dwarf star. When the accreted envelope reaches a "critical mass", hydrogen burns explosively and matter is accelerated outward. The evolution of the nova is conceptually simple, and can be divided into four stages.

A. The brightness of the white dwarf increases by a factor of $\sim$ 100 to 10^4 in a few hours to a few months. The radius of the white dwarf remains roughly constant at $\sim$ 0.01 $R_\odot$ as the luminosity increases.

B. A nova then expands to a radius of 1-100 $R_\odot$ at roughly constant luminosity ($\sim$ 100 to 10^4 $L_\odot$).

C. After $\lesssim$ 1-10 years at visual maximum, the symbiotic nova begins to exhaust its nuclear fuel and contracts back to its original radius.

D. The symbiotic nova eventually exhausts its fuel, and returns to its original luminosity.

Accretion events, as applied to symbiotic stars, involve rapid material flow from a large disk onto a solar-type main sequence star. The source of matter is the giant companion, but it is not clear if the giant initiates the eruption (by ejecting more matter than usual) or if material is stored in the disk between eruptions. The situation envisioned for accretion-driven outbursts in symbiotics thus resembles that of dwarf novae (discussed by Warner elsewhere in this issue) with two important differences from an observational standpoint.

A. Accretion events in symbiotics decline on an orbital time scale (1-5 years).

B. The shallow gravitational potential well of an accreting main sequence star (as compared to that of a white dwarf) results in a "soft" spectrum at maximum. Dwarf novae are typically very hot at maximum (T $\sim$ 10^5 K), but their symbiotic counterparts are much cooler (T $\sim$ 30,000 K).

The major observational difference between accretion events and thermonuclear runaways is the evolution of the spectrum near maximum light.

A. The continuum and emission line fluxes are correlated in an accretion event.

B. The total luminosity of a nova is constant. During phase (C) the visual light declines, while the ultraviolet and emission line luminosity increases.

Having described what *should* happen when a symbiotic star erupts, we move on to a description of what *actually* happened in recent outbursts of CH Cygni and RS Ophiuchi.

3. CH Cygni

CH Cyg appeared to be composed of an F-type shell star and an M giant until July 1984, when a 2 mag drop in visual brightness renewed interest in this unusual symbiotic (Taylor, Seaquist and Mattei 1986). The F-type shell spectrum disappeared in July 1984, while emission from He I and [O III] increased in intensity (Figure 1). It is interesting that the overall energy in the Hβ line *decreased* during the decline.

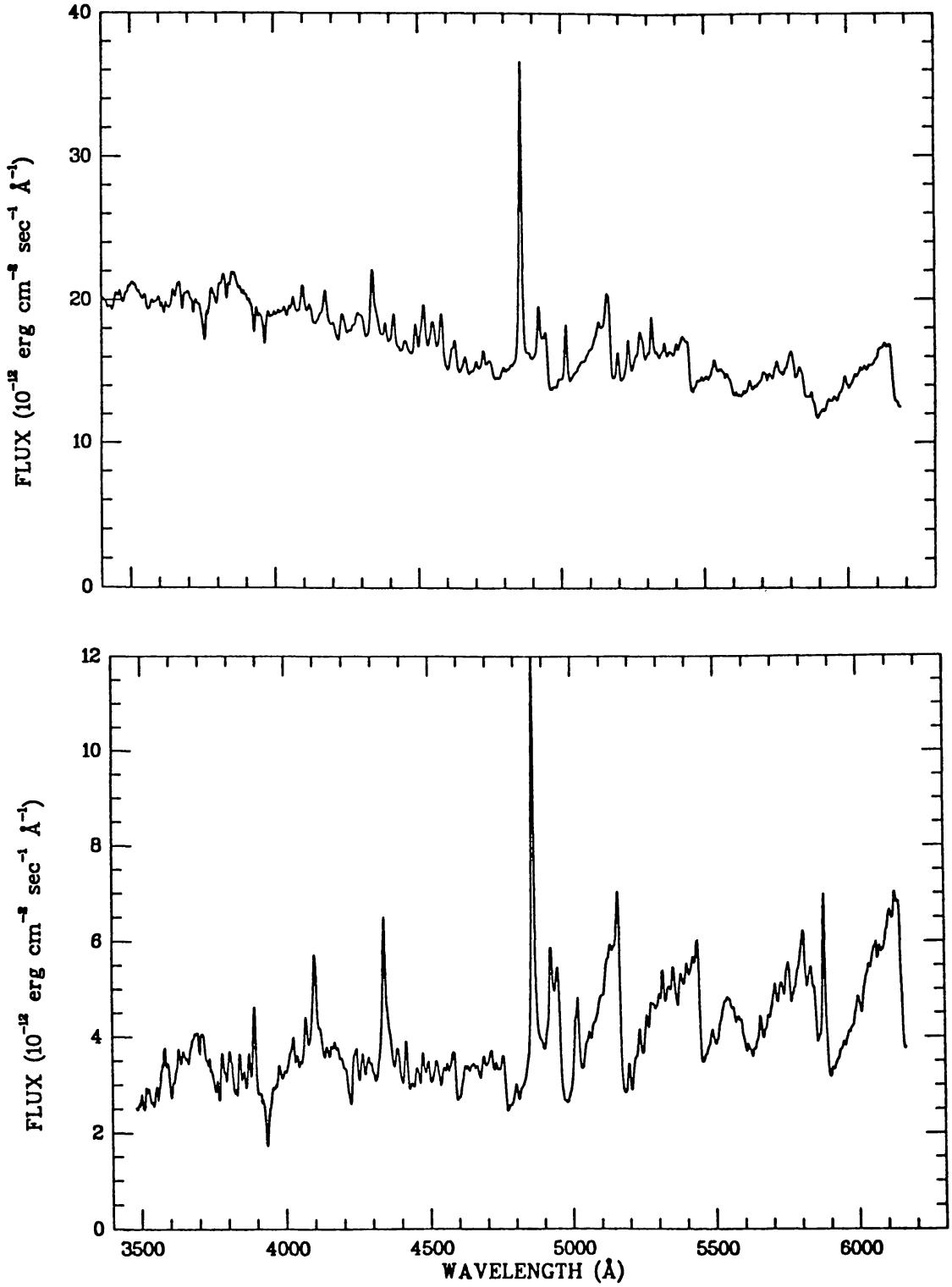

Figure 1 - Optical spectra of CH Cyg before (top panel) and after (bottom panel) the 1984 decline in visual brightness.

If the outburst of CH Cyg was the result of a normal thermonuclear runaway, the fading of the optical source should have been accompanied by an increase in the ultraviolet flux. However, the ultraviolet flux from the hot star *declined* by a factor of $\sim$ 5-10, while emission lines from He^{++}, C^{+3}, and O^{++} increased in intensity (Hack, *et al* 1986). The ratio of the He II λ1640 emission line intensity to that of Hβ indicates a source temperature exceeding 75,000 K, which is in stark contrast to the cool F-type photosphere visible before July 1984 (Kaler, Kenyon and Hickey 1983).

The optical and ultraviolet continuum activity described above are suggestive of the overall decline expected in an accretion event, but the evolution of the radio and X-ray data tell a different story. Taylor, Seaquist, and Mattei (1986) reported a radio detection of 0.3 mJy (1 mJy = 1 x 10^{-26} erg cm^{-2} Hz^{-1}) at a wavelength of 6 cm on 6 April 1984, but the intensity had risen to 20 mJy on 3 May 1985. This dramatic evolution in the radio was accompanied by a substantial increase in the X-ray flux, as *EXOSAT* detected CH Cyg where *Einstein* had failed to find an X-ray source. If the X-ray and ultraviolet continua are produced by a stellar source, CH Cyg contained a white dwarf with an effective temperature of $\sim$ 150,000 K during 1985-86.

The velocity widths of the optical emission lines increased to $\sim$ 1200 km s^{-1} during the optical decline, and Selvelli and Hack (1985) reported a velocity width of 4000 km s^{-1} for the ultraviolet Lα line. These velocities exceed the 100-200 km s^{-1} mass motions observed in quiescent symbiotic systems, and suggest that the fading of the optical source produced an ejection of material. Blobs of material moving away from the central source were resolved in the radio by Taylor, Seaquist, and Mattei (1986), and the rate of expansion of the blobs indicates a velocity of 1050/sin i km s^{-1} if the source has an inclination i and a distance of 400 pc.

The activity of CH Cyg is rather remarkable, since it appears that the source now emits many more high energy (X-rays) and low energy (radio) photons, but radiates far fewer medium energy (optical and ultraviolet) photons! It is fortunate that the infrared brightness remained constant, confirming that the cool giant is not responsible for the eruptive activity. Early interpretations for CH Cyg involved an accreting white dwarf, and observations of rapid variations on time scales of minutes supported models similar to those invoked for cataclysmic variables. Normal novae at maximum do not exhibit this "flickering" behavior, so CH Cyg is not a normal nova. However, if accretion is responsible for the recent maxima, CH Cyg would be the first instance of an accreting white dwarf producing a wind at *minimum light.* The continuum data suggest the source remained at roughly constant *total* luminosity during its optical decline, which is more reminiscent of a classical nova eruption than an accretion event. The recent behavior of CH Cyg contains features of thermonuclear runaways *and* accretion events, and thus defies a simple explanation.

A speculative scenario for this object involves both eruption mechanisms. Suppose CH Cyg once consisted of a low mass white dwarf accreting material from the wind of the red giant companion. The onset of a thermonuclear

runaway produces the observed luminosity of CH Cyg ($\sim$ 100 $L_\odot$) if the white dwarf mass is $\sim$ 0.52 $M_\odot$. Radiation pressure from the hot nova photosphere is not very large in CH Cyg at visual maximum, so, unlike other novae, the hot component can still accrete material from the red giant wind. Perhaps the flickering observed in CH Cyg prior to 1985 was a result of this continued accretion.

The onset of mass ejection during the decline remains difficult to explain in any scenario. It may be that the sudden temperature increase initiated the outflow, but continued observations will be needed to resolve this problem.

It is always difficult to test models for symbiotic stars, but the combined accretion/thermonuclear scenario does have one prediction: the mass of the hot component in CH Cyg should be $\sim$ 0.5 $M_\odot$. If the mass is much larger than this value, the luminosity at visual maximum could not have come from thermonuclear burning, because a more massive white dwarf would be much more luminous than CH Cyg was ever observed to be. It should be possible in the coming years to estimate the mass of the hot component by measuring the radial velocity variations of the giant, and thus test my proposal.

4. RS Ophiuchi

The fifth recorded eruption of the recurrent nova symbiotic RS Oph began in January 1985. The light curve for this event was nearly identical to that of previous eruptions (Kenyon 1986), and the rise and decline were so very rapid that it is not clear if the *actual* visual maximum was observed. It is interesting that while the primary maxima of RS Oph and another recurrent nova, T CrB, are nearly identical photometrically and spectroscopically, only T CrB shows a distinct secondary maximum.

Optical spectra of RS Oph in outburst are very spectacular compared to quiescent data, because emission lines from very highly ionized species dominate a weak continuum. The emission lines indicate an expansion velocity exceeding 1000 km s^{-1} at light maximum, and the montage of Hβ line profiles presented in Figure 2 demonstrates that the velocity of the ejected shell decelerates from $\sim$ 1000 km s^{-1} to $\sim$ 200 km s^{-1} in less than one month. This behavior is caused by nova ejecta colliding with a circumbinary nebula, and can be used to estimate that $\sim$ 10^{-7} $M_\odot$ is ejected in each outburst (Pottasch 1967). The multiple components visible in the optical and ultraviolet emission lines (Cassatella, *et al* 1985) indicate that material is not ejected in a spherically symmetric shell.

The ejection of $\sim$ 10^{-7} $M_\odot$ yr^{-1} moving at speeds in excess of 1000 km s^{-1} shocks the slowly moving material ($\lesssim$ 100 km s^{-1}) in the vicinity of the binary, and produces intense emission from [Fe X] and [Fe XIV]. X-ray data obtained by *EXOSAT* are consistent with two regions of shocked gas at temperatures of $\sim$ 3.5 x 10^6 K and $\sim$ 9 x 10^6 K (Mason, *et al* 1986). The total X-ray luminosity decayed from $\sim$ 100-200 $L_\odot$ to $\sim$ 5-10 $L_\odot$ in less than two months, but RS Oph was still a faint X-ray source $\sim$ 250 days after visual maximum.

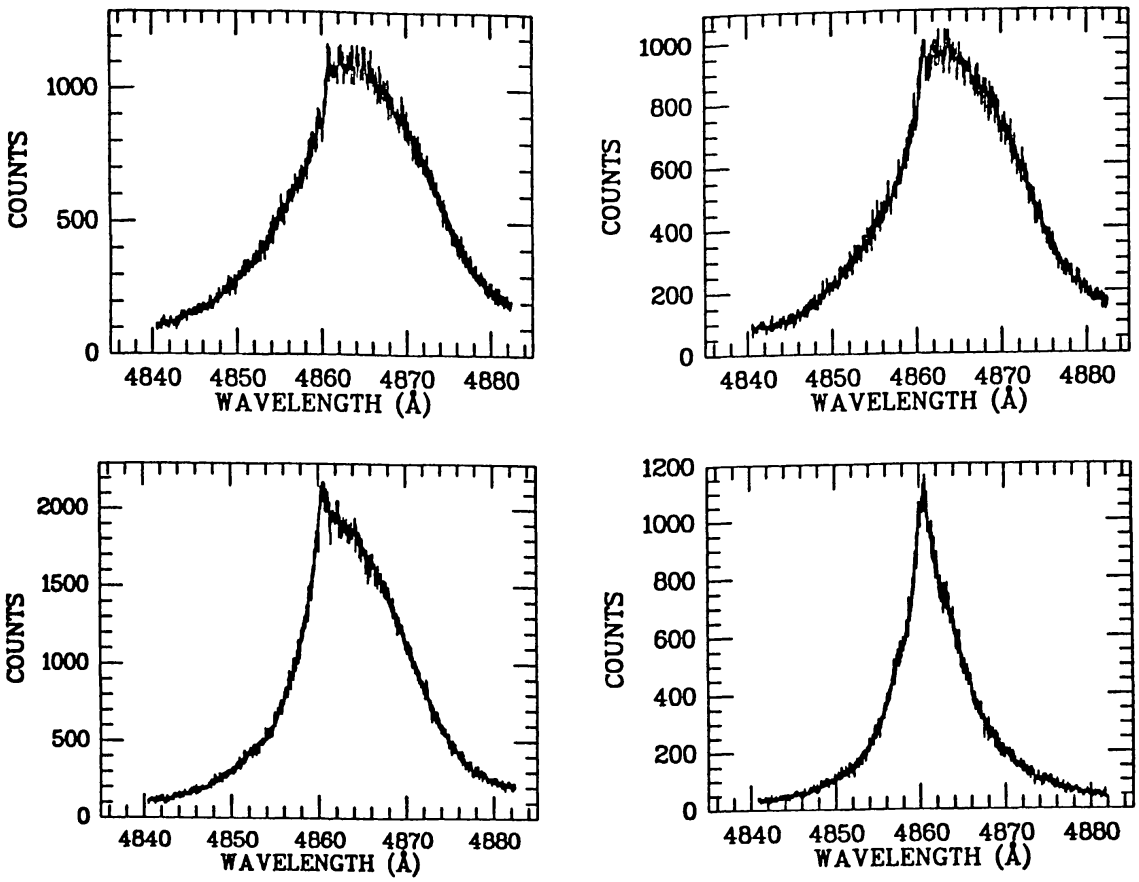

Figure 2 - Hβ line profiles in RS Ophiuchi. The data in the upper left panel were secured 4 days after optical maximum; other observations were made 5 (upper right), 10 (lower left), and 20 (lower right) days following visual maximum.

The radio intensity of RS Oph was fairly feeble before 1985 ($\lesssim$ 0.5 mJy), but peaked near 60 mJy at 6 cm following visual maximum (Hjellming, *et al* 1986). The decline was very complicated, with evidence for a non-thermal component at frequencies of 1.4-5 GHz and a thermal source at higher frequencies. It would be interesting if the two sources of radio emission are associated with the two X-ray regions discussed above.

Observations of RS Oph following visual maximum can be understood conceptually in terms of a rapid ejection of material into a less dense (but more massive) circumbinary envelope. The luminosity of the central source is $\sim$ 50,000 $L_\odot$ at visual maximum, which is similar to the brightness of an ordinary classical nova. The X-ray data at late epochs have been interpreted as thermal radiation from a hot white dwarf at a temperature of $\sim$ 300,000 K (Mason, *et al.*), and ejection velocities of $\sim$ 2000 km s^{-1} are appropriate for a white dwarf undergoing a thermonuclear runaway. Starrfield, Sparks, and Truran (1985) have shown that recurrent nova outbursts can be achieved with white dwarfs if the mass is very close to the Chandrasekhar limit of $\sim$ 1.4 $M_\odot$, so the simplest

explanation for the recurrent eruptions of RS Oph appears to be a thermonuclear runaway.

A thermonuclear runaway is, in fact, the most popular interpretation for the 1985 outburst of RS Oph, but there are still a few unanswered questions concerning the behavior of this symbiotic.

A. Enhanced abundances of C, N, O, and Ne in the ejecta of recent novae support models in which the fastest novae are produced by massive white dwarfs. If RS Oph's outbursts also result from runaways on a very massive white dwarf, why are emission lines from C, N, O, and Ne not prominent following visual maximum?

B. Classical novae typically show evidence for high velocity winds well after visual maximum ($v \gtrsim 2000$ km s^{-1}; Gallagher and Starrfield 1978), which are usually interpreted as continued ejection from the hot nova photosphere. If RS Oph is a nova, why are high velocity features not visible well after maximum?

C. Thermonuclear nova models increase in effective temperature following visual maximum (phase C). If the X-rays detected by Mason, *et al.* (1986) were produced by a hot white dwarf, why are emission lines from He II and other highly ionized species so very weak a few months after visual maximum?

D. Cataclysmic variables contain accreting white dwarfs, and their emission lines have velocity widths exceeding 2000 km s^{-1}. If the hot component in RS Oph is a white dwarf, why are the velocity widths of its quiescent emission lines less than 500 km s^{-1}?

E. The models of Starrfield, Sparks, and Truran (1985) require the white dwarf to accrete material at rates in excess of 10^{-8} $M_\odot$ yr^{-1} to obtain outbursts with the observed recurrence time of 15-20 years. If the hot component in RS Oph is accreting at such a large rate, why is the observed He II emission so much smaller than expected? The observed radio flux (<0.5 mJy) is also somewhat smaller than expected ($\sim$ 2 mJy).

Each of the inconsistencies with the thermonuclear model can be resolved if the outburst was initiated by an accretion event onto a main sequence star, but it may be difficult to achieve the observed ejection velocities in this model. Livio, Truran, and Webbink (1986) have proposed an intriguing idea in which a blob of matter lost by the giant *hits the hot companion directly*, instead of impacting an accretion disk as in dwarf novae. Such behavior commonly occurs in Algol binaries (Olson 1983), so the Livio, Truran, and Webbink proposal for RS Oph is really a scaled-up version of the physics which occurs in U Cep and other short period binaries. Livio, Truran, and Webbink require that $\sim 10^{-5}$ $M_\odot$ accretes onto a central main sequence star during the rise to visual maximum in RS Oph, and suggest that the resulting shock ejects a small fraction of the accreted material. The matter could also be ejected in a wind similar to that which occurs

in an O-B supergiant. A simple application of calculations for luminous O stars suggests that RS Oph could eject $\sim 10^{-5}\,M_{\odot}\,yr^{-1}$ at speeds of 2000 km s^{-1} for a few days following visual maximum, which is sufficient to produce all of the phenomena observed throughout the eruption.

As with CH Cyg, the available data for RS Oph do not allow a unique interpretation of the outburst. It is necessary to combine data from quiescent and eruptive phases to analyze this object, and it seems that an accretion model currently suffers fewer inconsistencies than do runaway models. However, RS Oph has not revealed its most valued treasures, and additional observations are needed to unlock its secrets.

5. Summary

In this review, I have discussed recent observations of two eruptive symbiotic stars, and have tried to illustrate the difficulties encountered when trying to interpret the data. I hope that members of the AAVSO are encouraged that their important discoveries of symbiotic eruptions provide professional astronomers with new insight (and new headaches!) into the phenomena of interacting binaries, and will continue to search for signs of activity in other less-publicized symbiotic systems. Outbursts in several symbiotic stars, including YY Her, V443 Her, RW Hya, and SY Mus, have never been reported, and I encourage amateurs with modest telescopes to watch for the first eruptions of these objects!!

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