6
The Symbiotic Stars
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6.1 Symbiotic Stars: Binaries accreting from a Red Giant

When Merrill and Humason [1932] discovered CI Cyg and AX Per, the first known symbiotic stars (hereafter SySts), they were puzzled (in line with the wisdom of the time, not easily contemplating stellar binarity) by the co-existence in the ‘same’ star of features belonging to distant corners of the HR diagram: the TiO bands typical of the coolest M giants, the HeII 4686 Å seen only in the hottest O-type stars, and an emission line spectrum matching that of planetary nebulae (hereafter PN). All these features stand out prominently in the spectrum of CI Cyg shown in Figure 6.1 together with its light-curve displaying a large assortment of different types of variability, with the spectral appearance changing in pace (a brighter state usually comes with bluer colors and a lower ionization).

A great incentive to the study of SySts was provided in the 1980ies by the first conference (Friedjung and Viotti, 1982) and monograph (Kenyon, 1986) devoted entirely to them, the first catalog and spectral atlas of known SySts by Allen (1984), and the first simple geometrical modeling of their ionization front (Seaquist et al., 1984). Allen offered a clean classification criterium for SySts: a binary star, combining a red giant (RG) and a companion hot enough to sustain HeII (or higher ionization) emission lines. The spectral atlas by Munari and Zwitter (2002), shows how the majority of SySts meeting this criterium display in their spectra emission lines of at least the NeV, OVI or FeVII ionization stages, requiring a minimum photo-ionization temperature of 130,000 K (Murset and Nussbaumer, 1994). For sometime a main sequence star accreting at a furious rate \(10^{-5} - 10^{-4} M_{\odot} \text{yr}^{-1}\) was advocated as the hot component of several symbiotic stars (Kenyon and Webbink, 1984; Mikolajewska and Kenyon, 1992), but this scenario was later abandoned in favor of a WD. Accretion onto a main-sequence star must apply instead to pre-SySts systems like 17 Lep which are in the first phase of mass transfer (Blind et al., 2011), when the AGB progenitor of the future WD transfers mass to a main sequence companion. As indicated by satellite observations (e.g. Munari and Buson, 1994), accretion alone cannot sustain the extreme luminosities \(10^{3} - 10^{4} L_{\odot}\) encountered in most SySts (Murset et al., 1991), and - given its high efficiency - nuclear burning at the WD surface must be invoked: burning 1 gr of hydrogen provides infact \(6 \times 10^{18}\) erg, while accreting the same 1 gr on a 1.3 \(M_{\odot}\) WD lib-

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Figure 6.1 Photometric and spectroscopic behavior of the prototype symbiotic star CI Cyg. Upper panels: the arrows mark the time for the two spectra shown, and the thick bars the passage at superior conjunction of the WD in the 855 days orbit around the M giant companion. The letter ‘a’ indicates an eclipse of the outbursting WD, while ‘b’ and ‘c’ minima in the irradiation-modulated light-curve. α, β and γ mark three separate outbursts of different amplitude, shape and duration. The fact that the $B - I$ color evolution follows the $B$ light-curve indicates how the M giant keeps stable while the activity resides entirely with the WD and the circumstellar gas ionized by it. Bottom panel: spectrum at outburst peak (2008 Sep 8) and at irradiation minimum (2015 Aug 13). Note the huge diversity in ionization degree (HeII, [NeV], [FeVII]), integrated flux of emission lines, and emission in the Balmer continuum (for this and all the following figures spectroscopy is provided by Asiago and Varese telescopes, and photometry by ANS Collaboration).

erates $6 \times 10^{17}$ erg, $6 \times 10^{16}$ erg on a 0.5 $M_\odot$ WD, and only $2 \times 10^{15}$ erg on a main-sequence star like the Sun.

Homogeneity did not last for long however, and by the time of the next catalog of SySts (Belezyński et al., 2000), systems with an excitation lower than HeII, and evidence from X-rays for a neutron star (NS) rather than a WD, begun percolating through the broadening classification criteria. Currently (Mukai et al., 2016), any binary where a WD or NS
accretes enough material from a RG companion such that this interaction can be detected at some wavelength is called a SySt. The number of known SySts is rapidly expanding (∼400, Akras et al., 2018), in particular as a consequence of surveys of the Galactic Bulge and Plane (Corradi et al., 2010; Miszalski et al., 2013; Rodríguez-Flores et al., 2014) and of galaxies in the Local Group (Angeloni et al., 2014; Mikolajewska et al., 2014, 2017).

6.2 Burning Symbiotic Stars

The amount of material burnt at the surface of the WD as been traditionally considered equal to that continuously accreted from the RG (eg. Kenyon, 1986), so that neither the nuclear burning switches-off (accretion too low), nor the envelope expands to red-giant dimension (accretion too high). The WD in burning SySts is however radiating close to its Eddington limit and accretion could fall quite shorter than required to replenish what the WD burnt. Either nuclear burning conditions are therefore met only temporarily (followed by an accreting-only interval to refuel the envelope of the WD) or the Eddington limit is circumvent by discrete accretion episodes like that of a massive disk dumping mass onto the WD during low-amplitude outbursts. The burning WD emits profusely super-soft X-rays, and indeed several SySts have been detected as SSS-sources, including C-1 in the Draco dwarf galaxy (Luna et al., 2013). Most however are not detected as SSS-sources, the super-soft X-rays being absorbed locally by the abundant circumstellar gas (a situation similar to the early evolution of novae, before the ejecta dilute and turn optically thin to super-soft X-rays from the burning WD at their center). The low impact made by accretion
in burning SySts is confirmed by the widespread absence of both flickering and signature of magnetic-driven accretion (Sokoloski, 2003; Zamanov et al., 2017).

The SySts (mostly those of the burning type) are the only known class of astronomical objects known to show OVI 1032, 1036 Å Raman-scattered by neutral hydrogen into a pair of broad emission features at 6825, 7088 Å (Schmid, 1989). A so far unique exception seems to be the Sanduleak’s Star in LMC, which partnership with SySts has been questioned (Angeloni et al., 2014). Other Raman-scattered lines from HeII 940, 972 and 1025 Å and NeVII 973 Å have been proposed for SySts (Lee et al., 2014). The simultaneous coexistence of OVI and neutral hydrogen can be offered only by the very extended wind (10^2 au) of a RG orbited within a few photospheric radii by a burning WD.

To accommodate a RG, the orbital separation in a SySt is measured in astronomical units rather than solar radii of cataclysmic variables. The orbital periods range mostly from 1 to 4 yrs, with a maximum at 2/3 yrs and an M5III spectral type for the RG. Most burning SySts in our Galaxy seems to belong to the metal-rich Bulge population (Whitelock and Munari, 1992, Gaia will soon tell) and are O-rich (M spectral types) as opposed to C-rich (Carbon spectral types) in the Magellanic clouds, a fact related to the lower metallicity of SMC/LMC and its impact on the amount of Carbon brought up by the third dredge-up on the AGB. Chemical abundances has been recently derived for several of the brightest SySts from near-IR spectra. They should be treated with caution given the adopted over-simplifications (thin, plane-parallel, static, LTE atmospheres) contrasting with the huge complication of real RGB/AGB atmospheres (non-LTE, shocked, wind-supported, macro-turbulent, and hugely 3D extended). In about 15% of known SySts, the RG is a Mira, of an average M7III spectral type, and with a pulsation period usually quite longer than for field Miras (Whitelock, 2003). To accommodate the Mira well within its Roche lobe so to allow a regular pulsation, the orbital period must be P ≥ 20 yrs. At such a wide orbital separation, no appreciable interaction would have occurred prior to the Mira evolutionary stage, with the binary system classified as an isolated, field RG. The Miras in SySts frequently come with warm dust (D-type SySts, as opposed to S-type with no detectable dust, and D’-type with cooler dust), which is believed to be preferentially located in the shadow cone created by the Mira itself, and possibly causing periodic obscurations along the orbital motion (Whitelock 2003), even if an alternative location in the collision zone between the winds from the Mira and the WD has been proposed (Hinkle et al., 2013), at least for the Miras in symbiotic novae.

The mass transfer from the RG to the WD of SySts can occur via either capture from wind or Roche-lobe overflow. SySts with Roche-lobe filling RG present ellipsoidal distorted light-curves at I-band or longer wavelengths, as illustrated in Figure 6.2, with an amplitude depending on orbital inclination and spectral type. For SySts with accreting-only WD, the ellipsoidal modulation dominates all the way down to bluest wavelengths (T CrB in Figure 6.2), while for burning SySts the irradiation by the WD of the facing side of the RG is responsible for the sinusoidal modulation dominating the bluest photometric bands. The amplitude of this modulation is proportional to the temperature and luminosity of the burning WD (cf. IV Vir and higher ionization LT Del in Figure 6.2).
The strong orbital dependence of the emission in the Balmer continuum (primarily responsible for the huge amplitude seen in the U band) suggests that an important fraction of the irradiation effect resides in the ionized gas between the WD and the RG (Proga et al., 1998), but at least in some cases a direct increase in the surface temperature of the irra-
diated side of the RG has been documented [Chakrabarty and Roche, 1997; Munari et al., 2016]. There are SySts showing no ellipsoidal distortion of the I or JHK light-curves while presenting deep eclipses of the WD during outbursts (eg. FG Ser). Their RG must resides well within the Roche lobe, and the WDs have therefore to accrete from the wind, as it is the case for SySts containing a pulsating Mira variable. Hydrodynamic simulations [Mohamed and Podsiadlowski, 2012] show that the wind can be confined within the RG’s Roche lobe and strongly focused toward the binary orbital plane. Such a wind Roche-lobe overflow (WRLOF) can be so efficient to allow the WD to accrete \( \sim 50\% \) of the RG’s mass loss and not just the few % typical of a Bondi-Hoyle-Littleton dynamical cross-section. The WRLOF, as other means of boosting the efficiency of mass accretion from wind [Bisikalo et al. 2006; Skopal and Carikova 2015; Pan et al. 2015], would also offer a way out to the evolutionary paradox posed by the yellow SySts. They are a small group, including both burning and accreting-only cases. Their RG are G/K-type giants, with Halo kinematics and low metallicity ([Fe/H] \( \leq -1 \)), enriched in s-type elements (most notably barium), which are normally brought to surface during third dredge-up at the tip of the AGB. They lack however the presence of unstable Tc isotopes and are less luminous than the tip of the AGB, indicating and extrinsic origin of the s-type elements, i.e. pollution from the progenitor of the current WD companion [Jorissen et al. 2005; Pereira et al. 2017]. Some of these SySts are rotating at a significant fraction of their rotational break-up velocities (\( V_{\text{rot}} \sin i \geq 100 \text{ km s}^{-1} \)), suggesting a massive transfer of both mass and angular momentum from the progenitor of the current WD. The distribution of orbital periods and eccentricities of Barium SySts require that dynamically unstable mass transfer by Roche lobe overflow (and the resulting common-envelope phase with its orbit shrinking and circularization), is avoided and massive transfer of mass and angular momentum be achieved via wind.

6.3 Accreting-only Symbiotic Stars

All-sky surveys as well as pointed X-ray observations (with the Swift satellite in particular) are discovering a population of optically unconspicous RG that emits in hard X-rays, a fact requiring them to pair in a binary system with a WD or a NS. Their relatively low X-ray (\( \approx 0.1-10 \text{L}_\odot \)) and UV (\( \approx 1-10 \text{L}_\odot \)) luminosities currently limits the serendipitous discovery to systems within \( \sim 1 \) kpc. A WD companion is usually associated with a luminosity larger in UV than in X-rays, while the reverse is true for a NS (given its deepest potential well). SySts are studied as potential progenitors of type Ia supernovae, since the original proposal by Munari and Renzini (1992), whose population synthesis was based on the estimated total number of burning SySts in the Galaxy, i.e. those easier to discover over vast distances thanks to their spectacular emission line spectrum. If burning SyST are just the tip of an iceberg of momentarily quiet, accreting-only SySts, the appeal of the symbiotic channel to SN Ia will be further boosted up.

The subtle way these low-key, optically-quite and accreting-only SySts are discovered
Table 6.1 *Different types of X-ray emission observed in Symbiotic Stars, their likely origin and some of the best known examples in each class.*

| Type | Description | Examples |
|------|-------------|----------|
| $\alpha$ | Super-soft, photon energies $\leq 0.4$ keV, hydrogen burning on WD surface | AG Dra, Draco C-1, SMC-3 |
| $\beta$ | Soft, photon energies $\leq 2.4$ keV, colliding winds from WD and red giant | Z And, Mira AB, AG Peg |
| $\delta$ | Hard, absorbed, with thermal emission detectable at $\geq 2.4$ keV, boundary layer between accretion disk and WD | SU Lyn, 4 Dra, T CrB |
| $\beta/\delta$ | Characteristics of both $\beta$ and $\delta$ type simultaneously present, from colliding winds and disk/WD boundary layer | NQ Gem, CH Cyg |
| $\gamma$ | Absorbed NS accretor, pulsed by NS spin, optically thick Comptonized plasma | GX 1+4, V934 Her |

is well epitomized by SU Lyn, a $V \sim 8$ mag, M6III giant at about 600 pc distance, completely unnoticed except for an old report about a possible SRB variability (AGB stars with a poorly defined periodicity and low amplitude). Looking for optical counterparts of *Swift*-BAT sources, Mukai et al. (2016) noted that SU Lyn lied within the error box of one of them. Follow-up observations were organized with *Swift* (to refine the astrometric position of the BAT source and better characterize its UV and X-ray emission) and with the Asiago spectrographs (to investigate if SU Lyn optical spectra could betray peculiarities supporting a physical association with the *Swift*-BAT source). Some results are summarized in Figure 6.3. While the optical spectrum of SU Lyn is identical to that of a normal M6III giant, its bluest part ($\lambda \leq 3900$ Å) shows a flux excess that extends to match the UV excess seen by *Swift* UVOT telescope and the soft and hard X-ray emission observed by *Swift* XRT and BAT instruments. Only high-resolution Echelle spectra can reveal a feeble, structured and quite variable emission in $H\alpha$.

Similar tortuous paths affect the discovery of SySts hosting a NS, usually named symbiotic X-ray binaries (or SyXBs; Masetti et al., 2007). SyXBs are quite rare: among the $\sim 200$ low-mass X-ray binaries (LMXBs) known in the Galaxy, only $\sim 10$ SyXBs cases are currently known. Observationally, these systems are characterized by appreciable X-ray emission ($\sim 10^{32} - 10^{34}$ erg s$^{-1}$) positionally associated with a RG star which spectroscopically does not show any abnormal features, with the possible exception of a continuum excess in the blue and ultraviolet ranges (similar to what illustrated in Figure 6.3 for SU Lyn). The X-ray emission is pulsed (periods from $10^2$ to $10^4$ seconds, 4U 1954+319 being the slowest at $P_{\text{spin}} \sim 18,400$ s), indicating that the NS is rotating slowly. The rotation period changes in response to accretion: for 4U 1954+319 Marcu et al. (2011) measured...
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a strong spin-up of $-1.8 \times 10^{-4}$ hr $^{-1}$ during outbursts and a spin-down of $2.1 \times 10^{-5}$ hr $^{-1}$ in quiescence. The level of X-ray emission can vary up to four orders of magnitude, suggesting accretion from an inhomogeneous stellar wind and possibly coupled with an highly elliptical orbit of the accretor. A notable outlier is GX 1+4, which emits in X-rays up $10^{37}$ erg s$^{-1}$, with $P_{\text{spin}} \sim 120$ s (Chakrabarty and Roche 1997), and an optical spectrum (Munari and Zwitter 2002) quite similar to those of burning SySts. A geometrically-thin and optically-thick accretion disk heavily irradiated by the hard X-rays from the central NS would provide the UV-source needed to photo-ionize the RG wind: plasma diagnostic shows in fact that the gas in GX 1+4 is ionized by thermal UV radiation ($T_{\text{ph}} \sim 85,000$ K) rather than the non-thermal X-ray power law expected from the central accreting NS.

An handy classification of the main types of X-ray emission seen in SySts has been introduced by Murset et al. (1997) and expanded by Luna et al. (2013) and Nuñez et al. (2016). It is summarized in Table 1 with the name of a few well known SySts in each class, and a compact description of the likely origin for the X-rays.

### 6.4 Different types of outburst in Symbiotic Stars

#### 6.4.1 Z-And or Classical Type

Normal SySts frequently enjoy outbursts, that usual come in trains of a few individual episodes separated by longer periods spent at quiescence. The example of CI Cyg in Figure 6.1 is indicative: three different maxima ($\alpha$, $\beta$, $\gamma$), of declining strength and duration, separated in time by $\sim 1$ orbital period. The previous train of multiple maxima ended in 1979. Also the spectral evolution depicted in Figure 6.1 is quite typical: compared to quiescence, the outburst spectrum is characterized by a lower ionization, a stronger hot continuum veiling the RG molecular spectrum, and a large increase in the integrated flux of the emission lines. The amplitude of the outburst is 2 or 3 mag in the $B$ band, and declines toward the red. The color evolution of CI Cyg in Figure 6.1 well illustrates how the outburst status is barely detectable in the $I$-band, where the flux is dominated by the RG at all phases. This type of frequent and multiple outbursts is called Z-type or Z-And type from Z Andromedae, a prototype SySt. Jets (frequently seen bi-polar in high-res spectra) have been observed in about 12 symbiotic stars (for 1/3 of them also spatially resolved; cf. the spectacular images for R Aqr by Schmid et al. (2017)), and in most cases they are associated to Z-And outbursts. The projected jet velocities are of the order of 1000–1500 km s$^{-1}$, equivalent to the escape velocity from the region closest to the central WD, with the noteworthy exception of MWC 560 where velocities $V_{\text{ej}} \geq 6,000$ km s$^{-1}$ were observed (Tomov et al. 1990). In response to the great differences seen in the jets from one object to another, a variety of launching mechanisms have been proposed and modelled (eg. Stute and Sahai 2007; Skopal et al. 2009; Tomov et al. 2011). Whereas RGs in SySts ro-
Figure 6.4 Two very different kinds of outburst in the same burning SySt: \(a\) is an accretion event, \(b\) an expansion of the burning shell once the accreted material reaches it. The arrows points to times for the representative spectra in the bottom panel. \(F_\lambda(\text{H}\alpha)\) is the integrated flux of H\(\alpha\) (in units of \(10^{-12}\) erg cm\(^{-2}\) s\(^{-1}\)), and \(T\) the photo-ionization temperature of the hot source.

tate faster than field RGs and appear synchronized with orbital period \(P_{\text{rot}} \approx P_{\text{orb}}\), those in systems emitting jets seem to rotate faster at \(P_{\text{rot}} < P_{\text{orb}}\) (Zamanov and Stoyanov, 2012).

As of the causes of Z-And type outburst, a great variety of different mechanisms have
been invoked (e.g., Bisikalo et al. 2006, Tomov et al. 2011, Skopal et al. 2011, Ramsay et al. 2016, de Val-Borro et al. 2017) like a sudden increase in the mass-transfer rate from the RG, either triggered by intrinsic variability of the RG or its passage at periastron; the formation of an optically thick, cool, disk-shaped zone around the WD equator as a consequence of enhanced wind from the WD; an enhanced wind from the WD which leads instead to the disruption of the inner part of the accretion disk with the formation of hollow cones around the WD axis of rotation and thus to the appearance of collimated outflows; changes in the kinematical regime of colliding winds from the WD and the RG, etc. A coordinated effort between X-ray, ultraviolet, optical, and radio observations to follow in detail and over all the relevant phases the Z-And outbursts of at least a few SySts seems required to raise firm constraints useful in guiding future modeling efforts.

Basically, the explanations for Z-And type outbursts tend to cluster into two broad categories: (a) release of potential energy from extra-accreted matter, or (b) shift to longer wavelengths of the emission from WD burning shell of the WD, expanding in radius as response to an increase in the mass accretion rate. Both modes could occur in succession in the same object, as illustrated in Figure 6.4 by the 2016/17 outburst of StHz 169.

6.4.2 Symbiotic Novae

A very few (~10) Symbiotic Novae (SyN) have been seen to erupt in historical times in our Galaxy, while others were already in outburst when discovered as SySts. They should not be confused with the novae erupting in symbiotic binaries described below. The outbursts of SyN last about a century, are of large amplitude and only one eruption has been recorded, with the possible exception of BF Cyg that shortly after returning to quiescence from the outburst initiated in 1894 (Leibowitz and Formiggini 2006), it started a new SyN cycle in 2006 and currently is still at maximum brightness.

The typical photometric and spectroscopic evolution of SyN are illustrated in Figure 6.5. A large rise in brightness takes the star, in about ~1 year, from faint anonymity to bright spotlight, from where an extremely slow decline needs about a century to return the system to quiescence level. The spectral evolution is equally slow. During the rise toward maximum, the spectrum cools up to an F-type supergiant with feeble emission lines limited to Balmer and FeII. During the decline, the F-type continuum weakens, a nebular continuum takes over and the emission lines grow in intensity and ionization degree. In few cases (e.g., HM Sge and V1016 Cyg), the phase dominated by the F-type supergiant continuum is probably too short and, when transiting at maximum brightness, the spectrum of the SyN is already dominated by a nebular continuum and strong emission lines.

A SyN outburst could even be the event that initiate a symbiotic-cycle in the life of a RG+WD binary, coming after a long and quiet period of accretion only. Under the high mass-transfer rates allowed by WRLOF or by plain Roche-lobe filling, the material should pile up in non-degenerate form on the surface of a nonmassive and hot WD. Upon reaching conditions for hydrogen burning, this will proceed under thermal equilibrium avoiding the
Figure 6.5 The $V$-band light-curve of the symbiotic nova V4368 Sgr (= Wakuda’s object) is given in the middle panel, with marked by arrows the epochs of the sample spectra shown in the bottom panel. For comparison, the upper panel displays the light-curve of V1016 Cyg, another SyN.

TNR of a classical nova and the consequent violent mass ejection. To adjust to the large nuclear luminosity produced at its base, the nondegenerate envelope expands to supergiant dimensions. The absence of massive ejection retains most of the mass in the WD envelope, which keeps burning under stable conditions for a long time, in excess of the ∼century a SyN takes to return to quiescence. AG Peg has only recently returned to pre-SyN brightness after the SyN outburst initiated around 1850: now it is a normal-burning SySt that experiences normal Z-And type outbursts (Tomov et al., 2016; Ramsay et al., 2016). If accretion
Figure 6.6 The peculiar spectral evolution of a nova erupting within a symbiotic binary (NwSySt) is well illustrated by the 2010 outburst of V407 Cyg. **Bottom:** portion of an Echelle spectrum obtained +2.3 days past optical maximum, with the simultaneous presence of very sharp (FWHM ≤ 20 km s⁻¹) and broad lines (FWHM ∼ 2700 km s⁻¹). Sharp lines are produced by recombination within the flash-ionized wind of the red giant. Broad lines come from the expanding ejecta of the nova. **Top:** sample of Hα profiles at various epochs showing the quick disappearance of the narrow component, the violent deceleration of the broad one, and the persistent presence of a narrow absorption originating in the outer wind of the RG unperturbed by the nova outburst.

cannot keep pace with hydrogen depletion by nuclear burning, sooner or later the shell on the WD in AG Peg will slim under the critical value, the burning will stop, and the star will move back to the anonymity typical of accreting-only SySts. After quietly accreting for an appropriately long interval, it will be ready for the next symbiotic cycle to be initiated by a new century-long SyN outburst.

### 6.4.3 Novae Erupting Within Symbiotic Stars

Under proper balance between mass loss and gain, the WDs of symbiotic stars can grow
in mass toward the Chandrashekar limit, with the bright prospect of concluding their life with a spectacular explosion as type Ia supernovae (Munari and Renzini, 1992). Approaching that limit, the WDs become so massive that normal nova explosions could occur on such a short time scale that more than one has been observed in historical times. Most famous recurrent novae among SySts are RS Oph (7 outbursts), V745 Sco (3), T CrB (2), and V3890 Sgr (also 2 outbursts).

A nova erupting within a SySt (NwSySt) evolves quite differently from a classical one. When the TNR culminates with an intense UV flash (Starrfield et al., 2016), the RG wind absorbs most/all of it, get ionized, and soon start glowing under recombination. The NwSySt is taken almost instantaneously to peak optical brightness, whereas in classical novae the UV flash disperses in the surrounding emptiness and goes unnoticed hours/days before the nova is discovered, and well before peak brightness is attained at the time of maximum expansion for the pseudo-photosphere of the optically thick ejecta. Given the large electron density in the wind of the RG at the distance it is orbited by the WD ($10^6–10^8$ cm$^{-3}$), the recombination from the UV flash proceeds rapidly in NwSySts (e-folding time 3–6 days). The recombining wind is not kinematically perturbed, consequently the lines it emits remain very sharp (FWHM $\approx 20$ km s$^{-1}$). In the meantime, material is ejected at high velocity from the central nova (FWHM of thousands km s$^{-1}$), producing very wide emission lines (of the He/N nova type) co-existing with the narrow ones (Figure 6.6, bottom panel). The fast ejecta ram onto the pre-existing wind of the RG, and upon sweeping it up they are violently decelerated causing a rapid narrowing of the broad-lines profiles (e-folding time of a few days; Figure 6.6 top panel). $\gamma$-rays in the GeV range are then produced as a consequence of the violent shock. The best documented NwSySt eruption is probably that of 2010 for the symbiotic Mira V407 Cyg (Munari et al., 2011; Pan et al., 2015).

References

Akras, S., Guzman-Ramirez, L., Leal-Ferreira, M., Ramos-Larios, G. 2018. A new symbiotic stars catalogue using 2MASS and WISE. I. MNRAS, submitted.

Allen, D. A. 1984. A catalogue of symbiotic stars. Proc. Astron. Soc. Australia, 5, 369–421.

Angeloni, R., and 12 colleagues 2014. Symbiotic stars in OGLE data - I. Large Magellanic Cloud systems. MNRAS, 438, 35–48.

Belczyński, K., Mikolajewska, J., Munari, U., Ivison, R. J. and Friedjung, M. 2000. A catalogue of symbiotic stars. A&AS, 146, 407–435.

Bisikalo, D. V., Boyarchuk, A. A., Kilpio, E. Y., Tomov, N. A., Tomova, M. T. 2006. A study of the outburst development in the classical symbiotic star Z And within the colliding-winds model. ARep, 50, 722–732.

Blind, N., Boffin, H. M. J., Berger, J.-P., Le Bouquin, J.-B., Mérand, A., Lazareff, B., Zins, G. 2011. An incisive look at the symbiotic star SS Leporis. Milli-arcsecond imaging with PIONIER/VLTI. A&A, 536, A55.

Chakrabarty, D., Roche, P. 1997. The Symbiotic Neutron Star Binary GX 1+4/V2116 Ophiuchi. ApJ, 489, 254–271.
Murset, U., Nussbaumer, H., Schmid, H. M., Vogel, M. 1991. Temperature and luminosity of hot components in symbiotic stars. A&A, 248, 458–474.

Murset, U., Wolff, B., Jordan, S. 1997. X-ray properties of symbiotic stars. A&A, 319, 201–210.

Nuñez, N. E., Nelson, T., Mukai, K., Sokoloski, J. L., Luna, G. J. M. 2016. Symbiotic Stars in X-Rays. ApJ, 824, 23.

Pan, K.-C., Ricker, P. M., Taam, R. E. 2015. Simulations of the Symbiotic Recurrent Nova V407 CYG. I. Accretion and Shock Evolutions. ApJ, 806, 27.

Pereira, C. B., Baella, N. O., Drake, N. A., Miranda, L. F., Roig, F. 2017. High-resolution Optical Spectroscopic Observations of Four Symbiotic Stars: AS 255, MWC 960, RW Hya, and StHα 32. ApJ, 841, 50.

Proga, D., Kenyon, S. J., Raymond, J. C. 1998. Illumination in Symbiotic Binary Stars: Non-LTE Photoionization Models. II. WIND Case. ApJ, 501, 339–356.

Ramsay, G., Sokoloski, J. L., Luna, G. J. M., Nuñez, N. E. 2016. Swift observations of the 2015 outburst of AG Peg. MNRAS, 461, 3599–3606.

Rodríguez-Flores, E. R., and 8 colleagues. 2014. IPHAS and the symbiotic stars. III. A&A, 567, A49.

Schmid, H. M. 1989. Identification of the emission bands at 6830, 7088 Å. A&A, 211, L31–L34.

Schmid, H. M., and 42 colleagues 2017. SPHERE/ZIMPOL observations of R Aqr. I. Imaging of the stellar binary and the innermost jet clouds. A&A, 602, A53.

Seaquist, E. R., Taylor, A. R., Button, S. 1984. A radio survey of symbiotic stars. The Astrophysical Journal 284, 202-210.

Skopal, A., Cariková, Z. 2015. Wind mass transfer in S-type symbiotic binaries. I. Focusing by the wind compression model. A&A, 573, A8.

Skopal, A., Pribulla, T., Budaj, J., Vittone, A. A., Errico, L., Wolf, M., Otsuka, M., Chrestina, M., Mikulášek, Z. 2009. Transient Jets in Z And. ApJ, 690, 1222–1235.

Skopal, A., and 14 colleagues. 2011. Formation of a disk structure in the symbiotic binary AX Persei during its 2007–10 precursor-type activity. A&A, 536, A27.

Sokoloski, J. L. 2003. Rapid variability as a diagnostic of accretion and nuclear burning in symbiotic stars and supersoft X-ray sources. ASPC, 303, 202–217

Starrfield, S., Iliadis, C., Hix, W. R. 2016. The Thermonuclear Runaway and the Classical Nova Outburst. PASP, 128, 051001.

Stute, M., Sahai, R. 2007. Hydrodynamical Simulations of the Jet in the Symbiotic Star MWC 560. III. Application to X-Ray Jets in Symbiotic Stars. ApJ, 665, 698–706.

Tomov, N. A., Bisikalo, D. V., Tomova, M. T., Kil’Pio, E. Y. 2011. Interpretation of the Line Spectrum of Classical Symbiotic Stars. AIPCS, 1356, 35–44.

Tomov, T., Kolev, D., Zamanov, R., Georgiev, L., Antov, A. 1990. MWC560 - A unique astrophysical object. Nature, 346, 637.

Tomov, T. V., Stoyanov, K. A., Zamanov, R. K. 2016. AG Pegasi: now a classical symbiotic star in outburst ?. MNRAS, 462, 4435–4441.

Whitelock, P. A. 2003. A Comparison of Symbiotic and Normal Miras (invited review talks). ASPC, 303, 41–56

Whitelock, P. A., Munari, U. 1992. Photometric properties of symbiotic stars and the nature of the cool component. A&A, 255, 171–180.

Zamanov, R. K., Stoyanov, K. A. 2012. Rotation of the red giants and white dwarfs in symbiotic binary stars. Bulg.A.J, 18, 41–52

Zamanov, R. K., and 11 colleagues 2017. Discovery of optical flickering from the symbiotic star EF Aquilae. AN, 338, 680–685.