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SPECTROSCOPIC OBSERVATIONS OF THE SYMBIOTIC BINARY RW HYDRAE

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ABSTRACT

We present contemporaneous ultraviolet/optical spectrophotometry and infrared photometry for the symbiotic binary RW Hya. The cool component is an M giant with $L \approx 1000\ L_\odot$ and $\dot{M} \approx 8 \times 10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$. The hot component is a compact star with $T_h \approx 70{,}000$–$90{,}000$ K and $L \approx 200\ L_\odot$. This luminosity is produced by a nuclear shell source, which is replenished by the wind of the red giant at a rate of $\sim 10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$. A large H II region ($R \approx 10$ AU) surrounds the binary system, and is the source of weak radio emission. The He^{+2} and O^{+2} regions are confined to the immediate vicinity of the hot component and have radii of ~ 1–3 AU.

Subject headings: Stars: binaries — stars: individual (RW Hya) — stars: symbiotic

I. INTRODUCTION

RW Hydrae (HD 117970) was discovered as an original symbiotic star when Merrill and Humason (1932) identified He II λ4686 emission on a low-resolution spectrum of a red variable star. TiO absorption bands and a strong red continuum were prominent on higher resolution optical spectra, and emission lines from H I, He I, [O III], and [Ne III] have been detected by various observers (Merrill 1933, 1940; Swings and Struve 1941; Bidelman and MacConnell 1973; Henize 1976). More recent ultraviolet spectra have revealed the strong continuum of a hot companion to the red giant star, as well as emission lines from C III], O III], C IV, and N V (Kafatos, Michalitsianos, and Hobbs 1980, hereafter KMH; Slovak 1982). The temperature of this source has been estimated at $\sim 10^5$ K (KMH; Slovak 1982; Kenyon and Webbink 1984, hereafter KW), but RW Hya has not been detected at X-ray wavelengths.

RW Hya was observed regularly in the early 1900s, and was found to vary from $m_{pg} = 10$ to $m_{pg} = 11$ (Townley, Cannon, and Campbell 1928). Garcia (1986) confirmed radial velocity variations suspected by Merrill and was able to phase Merrill's (1933, 1940) data and recent observations with the photometric ephemeris derived by KW ($P = 372^{\mathrm{d}}.45$). This result suggests that the optical variability is a result of orbital motion, perhaps via the reflection effect as in AG Peg (Belyakina 1970) or an eclipse as in CI Cyg (Belyakina 1979). Additional observations are needed to determine the orbital parameters, and to constrain the nature of the photometric variations.

RW Hya has never been observed to undergo an outburst, which is unusual for a symbiotic binary (Kenyon 1986, Appendix). Since eruptive activity in symbiotic stars is associated with extensive mass loss, this system presents an opportunity to examine the underlying binary in some detail. To this end, we have obtained high-quality spectrophotometric data which allow us to analyze the complete energy distribution for this "simple" symbiotic system. Our analysis confirms that RW Hya is a binary comprised of an M giant and a compact object which resembles the central star of a planetary nebula. This hot component accretes matter from the wind of the red giant, and it is this hydrogen-rich material that powers the nuclear luminosity of the compact source. We find that the binary is surrounded by an H II region with a radius of ~ 15 AU, which gives rise to the observed emission lines and radio emission.

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II. OBSERVATIONS

a) Ultraviolet Spectrophotometry

Low-resolution observations of RW Hya were made through the $10'' \times 20''$ aperture of the *International Ultraviolet Explorer* (*IUE*) satellite on 1985 June 20. The short (5 minute) exposures have been placed on an absolute flux scale using the calibration described by Holm *et al.* (1982) and combined into the spectrum presented in Figures 1–2. The continuum is well exposed (except near 2200 Å), and rises sharply toward shorter wavelengths. High-ionization emission lines are well marked on this spectrum and fluxes for the nonsaturated lines are summarized in Table 1.

b) Optical Spectrophotometry

Optical spectrophotometric observations of RW Hya have been obtained over the past 2 yr with the cooled dual-beam intensified Reticon scanner (IRS) mounted on the white spectrograph of the KPNO No. 1 90 cm telescope. Observations of five to six standard stars were made each night to place the data on the Hayes and Latham (1975) flux scale; the photometric calibration is accurate to ± 0.03 mag. These data are shown in Figures 1–2, while integrated fluxes for the obvious emission features are listed in Table 2.

c) Infrared Photometry

Near-infrared photometry of RW Hya was secured on 1985 June 5 and 1986 April 17–21 with the Hermann and Otto InSb

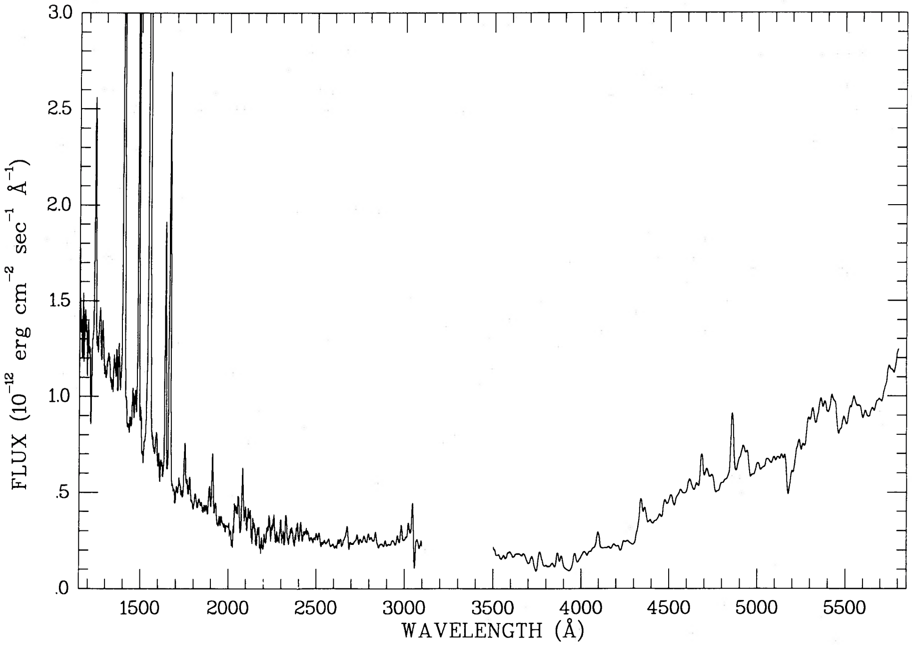

FIG 1*a*

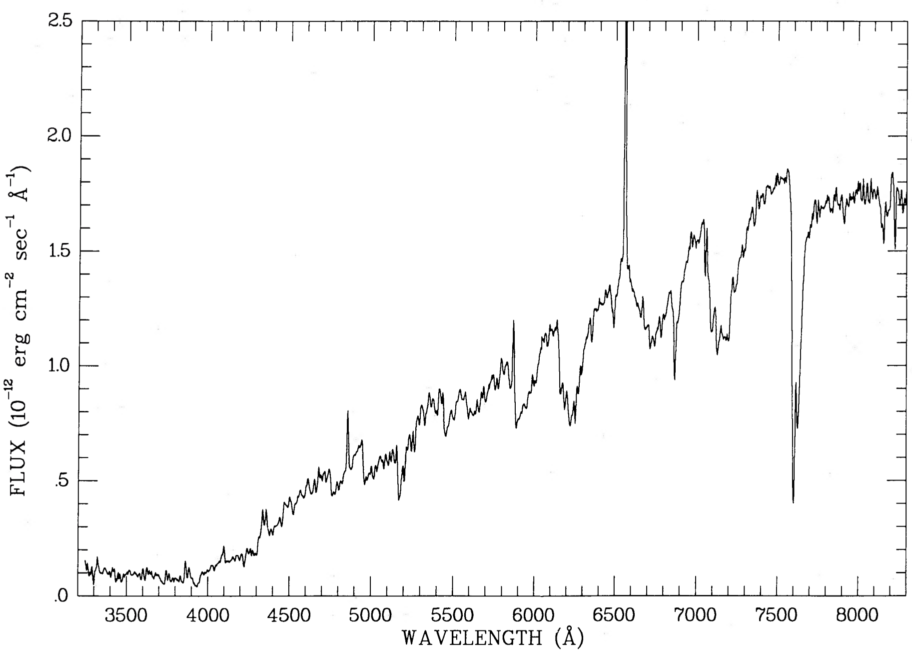

FIG 1*b*

FIG. 1.—Spectral energy distributions for RW Hydrae. (*a*) Data from 1985 June, as obtained with *IUE* and the KPNO IRS. (*b*) Optical spectra from 1984 April.

photometers mounted on the KPNO 1.3 m telescope. These data agree very well with measurements tabulated by Kenyon and Gallagher (1983); average fluxes have been plotted in Figure 2 using the absolute calibration listed by Rydgren, Schmelz, and Zak (1984). We have found no evidence for large amplitude (> 0.1 mag) variations in the near-infrared, which is consistent with the results discussed by Feast, Robertson, and Catchpole (1977).

RW Hya was observed with the *Infrared Astronomy Satellite* (*IRAS*), and Kenyon, Fernandez-Castro, and Stencel (1987) reported detections at 12 μm and at 25 μm. The color-corrected fluxes at these wavelengths (Hacking *et al.* 1985) have been determined from the absolute calibration described in the *IRAS Catalogs and Atlases, Explanatory Supplement*, and are 0.59 Jy at 12 μm and 0.26 Jy at 25 μm. Additional details concerning *IRAS* data for RW Hya and other symbiotic

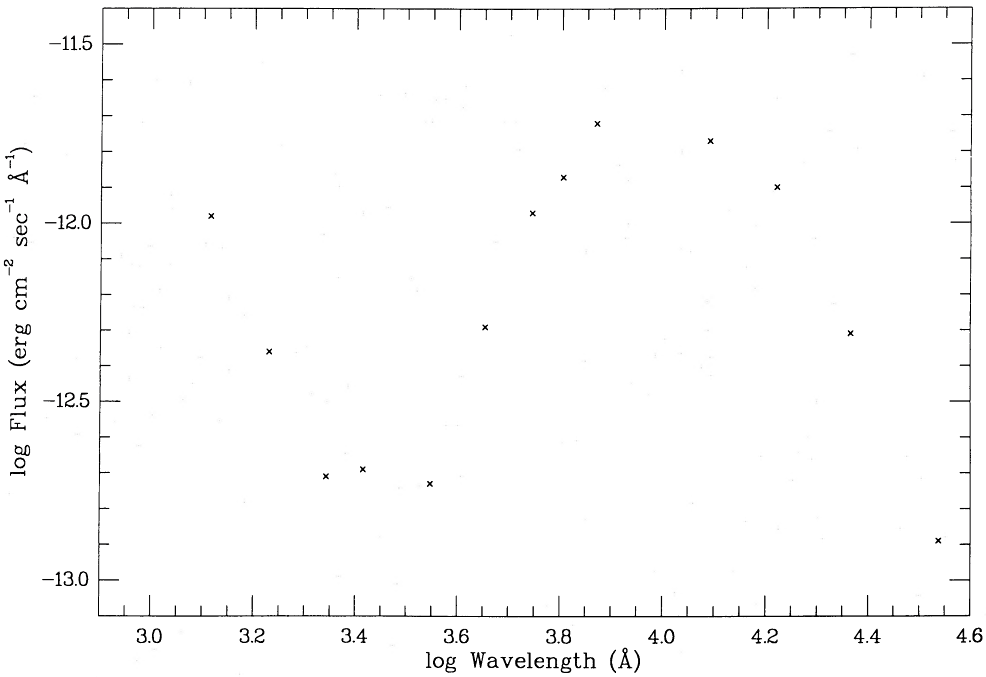

FIG. 2.—Continuum energy distribution for RW Hya. Continuum measurements from ultraviolet and optical spectra have been combined with broad-band IR photometry. In the absence of significant reddening, the cool component in RW Hya is clearly more luminous than the hot, compact companion. Various estimates suggest that interstellar and circumbinary materials do not significantly extinct light from this system.

systems are described in Kenyon, Fernandez-Castro, and Stencel (1986, 1987).

III. ANALYSIS

a) *Variability*

Ultraviolet spectra of RW Hya have been discussed previously by KMH and Slovak (1982). Our *IUE* spectra are qualitatively similar to data presented in both of these efforts, but the continuum is somewhat weaker in 1985 June than in 1979 July–September (KMH) or 1981 January (Slovak 1982). The ultraviolet emission lines in 1985 June are roughly a factor of 2 weaker than in 1979, and the O III lines at $\lambda\lambda$3047, 3133 weakened by a factor of ~ 6 in this interval.

The optical emission features also show marked variability, since the Balmer lines fluctuated by a factor of ~ 2 over a 1 yr time scale (Table 2). He II λ4686 appears to show more dramatic changes: it was not obviously visible in 1984 April but appeared in 1985 June as a strong emission feature. The "minimum" in He II occurred near phase 0.2 of the photometric ephemeris presented by KW, which is $\sim 30\%$ of a cycle before light minimum. The variations are *not* associated with the cool component: the *V* magnitude has remained nearly constant, while the brightness of the continuum at 3500 Å changed by a factor of 2. An archival study of the available *IUE* spectra and optical photometry might be able to determine if the long-term optical photometric behavior is connected with variability in the emission lines or the UV continuum.

b) *The Cool Component*

The nature of the late-type giant star is an important constraint on binary models for symbiotic stars, because the size of

TABLE 1

ULTRAVIOLET EMISSION LINES IN RW HYA ON JD 2,446,237

Identification	Line Flux[a]
N V λ1240	1.2
O IV] λ1401	2.9
Si IV λ1407	1.0
N IV] λ1487	2.9
C IV $\lambda\lambda$1548, 1550	9.8
He II λ1640	1.0
O III] $\lambda\lambda$1661, 1667	2.0
N III] λ1751	0.3
Si III] λ1891	0.2
C III] λ1909	0.3
O III λ3045	0.2
O III λ3131	0.5

[a] In units of 10^{-11} ergs cm^{-2} s^{-1}.

TABLE 2

OPTICAL EMISSION LINE FLUXES IN RW HYA[a]

Identification	1984 April 9, 12	1985 June 2
H9	0.3	0.4
[Ne III] λ3863	1.1	1.3
H8, He I λ3888	0.7	1.1
Hδ, N III λ4097	1.2	1.8
[Fe II] λ4320	0.9	1.1
Hγ	1.6	2.8
[O III] λ4363	1.7	1.6
He II λ4686	<1.0	2.4
Hβ	2.7	4.8
He I λ5876	4.4	...
Hα	16.7	...
He I λ6678	1.6	...
He I λ7065	2.0	...

[a] In units of 10^{-12} ergs cm^{-2} s^{-1}.

this component determines if mass loss occurs via tidal overflow or in a wind (see Plavec 1982; Kenyon and Gallagher 1983; Kenyon 1986, chap. 3). Our analysis of the optical absorption spectrum (Kenyon and Fernandez-Castro 1987) confirms the M2 spectral type assigned by Merrill (1933). Merrill later noted variations in the spectral type between M0 and M2, but our data are not sufficient to confirm fluctuations in the spectral type.

Kenyon and Gallagher (1983) noted that the strength of the 2.3 μm CO absorption band in RW Hya is comparable to band strengths in normal M giants rather than bright giants or supergiants. More recent CO observations tend to confirm these conclusions, although there are indications that the CO band strength is variable (Kenyon 1987). The *IRAS* data show that RW Hya has small excesses at 12 μm and 25 μm; the observed 2.2 μm–12 μm flux ratio is $F_\nu(2.2\ \mu m)/F_\nu(12\ \mu m) = 9.7$, while the 25 μm–12 μm flux ratio is $F_\nu(12\ \mu m)/F_\nu(25\ \mu m) = 0.43$. Typical values of $F_\nu(2.2\ \mu m)/F_\nu(12\ \mu m)$ and $F_\nu(25\ \mu m)/F_\nu(12\ \mu m)$ for normal M giants are 11.9 and 0.26, respectively (Kenyon, Fernandez-Castro, and Stencel 1987); mean values for $\sim$20 symbiotic stars with stellar near-infrared continua (the *S-type* symbiotics) are $\langle F_\nu(2.2\ \mu m)/F_\nu(12\ \mu m)\rangle = 9.1 \pm 2.1$ and $\langle F_\nu(25\ \mu m)/F_\nu(12\ \mu m)\rangle = 0.36 \pm 0.08$. The excess 12 μm and 25 μm emission in symbiotic stars appears to be the result of enhanced mass loss, which might be induced by the binary potential or by the advanced evolutionary state of the giants in these binaries (see Kenyon and Fernandez-Castro 1987).

If RW Hya contains a normal giant, we can estimate its distance from its *K*-magnitude and spectral type. We assume that all the radiation at 2.2 μm ($K = 4.7$) is produced by the giant, and derive $m_{\rm bol} = 7.4$ using the appropriate bolometric correction (Frogel, Persson, and Cohen 1981). Since $M_{\rm bol}$(M2 III) ≈ -2.2 (Schmidt-Kaler 1982), the distance is $\sim$830 pc. This distance is the minimum distance to RW Hya, since the cool component may be more evolved than a typical red giant star.

An upper limit to the distance can be derived from the observed *K*-magnitude, the spectral type, and Roche geometry. If the effective temperature of an M2 giant is 3730 K (Ridgway *et al.* 1980), the angular diameter of the giant in RW Hya is 0.66 mas using the appropriate Barnes-Evans relation for the *K*-magnitude (Cahn 1980). The cool component cannot be larger than its Roche lobe, which has a radius of $\sim 100\ R_\odot$ if the mass of both components is $\sim 1\ M_\odot$ and the orbital period is 372.45 d (KW). The maximum distance to RW Hya is therefore $\sim$1.5 kpc, close to that estimated from the *V*-magnitude (which is contaminated by radiation from the hot component) by KMH. We will adopt a distance of 1 kpc for the remainder of this paper.

c) *The Hot Component*

Radiation from the hot component dominates the short wavelength *IUE* spectrum ($\lambda\lambda$1300–2400), while nebular emission contributes significantly at longer wavelengths ($\lambda\lambda$2600–3300). We follow KW and measure continuum fluxes at 1300, 1700, 2200, and 2600 Å. We find $m_{1300} = 8.85 \pm 0.04$, $m_{1700} = 9.80 \pm 0.07$, $m_{2200} = 10.68 \pm 0.37$, and $m_{2600} = 10.61 \pm 0.04$, where $m_\lambda = -2.5 \log F_\lambda - 21.1$. The reddening-free color indices developed by KW are $C_1 = -0.98 \pm 0.15$ and $C_2 = -0.02 \pm 0.06$, which are consistent with a hot component having an effective temperature, $\log T_h = 4.86 \pm 0.09$ ($T_h \approx$ 72,500 K) reddened by $E_{B-V} = 0.03 \pm 0.06$. The radius of the hot component implied by our data is $\log R_h/R_g = -2.90 \pm 0.02$; thus $R_h \approx 0.08\ R_\odot$ and $L_h \approx 160\ L_\odot$ for a distance of 1 kpc.

An independent temperature estimate for the hot component can be derived from the He II λ1640 flux and the continuum flux. If I_{1640} is the observed flux of the He II λ1640 feature (in ergs cm^{-2} s^{-1}) and F_{1300} is the continuum flux at 1300 Å (in ergs cm^{-2} s^{-1} Å^{-1}), the effective temperature of the hot star can be derived from:

$$T^3_{\rm He^+} f(T_{\rm He^+})(e^{110677/T_{\rm He^+}} - 1) = 7.1 \times 10^{11} I_{1640}/F_{1300}\ , \quad (1)$$

where $f(T_{\rm He^+})$ is the ratio of the number of He$^+$-ionizing photons to the total number of photons emitted by a blackbody having a temperature $T_{\rm He^+}$. This expression is not very sensitive to the adopted value for the nebular electron temperature ($T_e = 20{,}000$ K), because $T_{\rm He^+}$ changes by $\sim$10% or less if T_e varies by a factor of 2. Equation (1) is more sensitive to our assumption that the nebula is optically thin in the He II lines and the Balmer continuum, and the optical depth estimates discussed below indicate that this assumption is not entirely valid. Nevertheless, our data for I_{1640} and m_{1300} result in $T_{\rm He^+} \approx 70{,}000$ K, which is comparable to the T_h derived above from the (C_1, C_2) indices.

A final estimate of T_h can be obtained from the optical He II λ4686 and Hβ emission lines. If both the H I and He II Lyman continua are optically thick, the ratio of line fluxes is simply

$$I_{4861}/I_{4686} = 0.6 N_{\rm H}/N_{\rm He^+}\ , \quad (2)$$

where $N_{\rm H}/N_{\rm He^+}$ is the ratio of the number of H and He$^+$ ionizing photons (Kenyon 1986, chap. 2). This ratio is a function of the effective temperature of the ionizing source (Osterbrock 1974), and our measured value of $I_{4861}/I_{4686} \approx 2$ in 1985 June implies $T_h = 150{,}000$ K for $T_e = 20{,}000$ K (see also Iijima 1981). This result assumes that Hβ and λ4686 are optically thin; the temperature is an upper limit if Hβ is optically thick.

The data currently point to a mildly variable hot component, since m_{1300} has varied by $\sim$0.5 mag over the past 6 yr. Fluctuations in m_{1300} appear to be correlated with the effective temperature derived from the C_1, C_2 color indices: $T_{\rm eff} \approx$ 90,000 K when $m_{1300} = 8.62$, and $T_{\rm eff} \approx 70{,}000$ K when $m_{1300} = 8.85$. The He II Zanstra temperature derived from equation (1) was $T_{\rm He^+} \approx 75{,}000$ K on 1979 July 29 (KMH), which is close to the $T_{\rm He^+} \approx 70{,}000$ K derived from our data. These variations are comparable to the calibration errors of the *IUE*, so an analysis of other *IUE* images is needed to quantify the extent of UV continuum and emission-line variability in RW Hya.

d) *The Nebula*

RW Hya does not have many strong forbidden or intercombination emission lines, and thus we cannot make detailed estimates for the electron density or electron temperature within the ionized nebula. The O III] $\lambda\lambda$1661–1667 blend is prominent on our *IUE* spectrum, but only [O III] λ4363 is obvious in the optical data. The lack of a strong λ2322 [O III] line requires $n_e \sim 10^8$ cm^{-3}, while the $\lambda4363/(\lambda1661 + \lambda1667)$ intensity ratio implies $n_e \approx 1$–3×10^8 for $10{,}000 < T_e < 40{,}000$ K (Nussbaumer and Storey 1981). This result is comparable to the $n_e \approx 10^8$–10^9 cm^{-3} deduced by KMH from a consideration of the complete UV emission spectrum. The overall weakness of the optical λ4959 and λ5007 lines favors high electron temperatures in 1985 June; if we make the reasonable assumption that the $\lambda 4363$ to $\lambda 5007$ intensity ratio is ~ 3 or greater, $T_e \gtrsim 20{,}000$ K. The observed line intensities imply a radius of $R_{\mathrm{O}^{+2}} \approx 2.9$–1.4 AU if $n_e = 1$–3×10^8 cm^{-3}, O/H $\approx 7 \times 10^{-4}$, and all of the oxygen is in the form of O^{+2} inside $R_{\mathrm{O}^{+2}}$. Most of the oxygen will be in the form of O^{+4} and O^{+3} near the central star, so the O^{+2} region is really a thick shell with inner radius $R_{\mathrm{O}^{+2},1}$ and outer radius $R_{\mathrm{O}^{+2},2}$ (see Osterbrock 1974, p. 30). The ionization structure presented by Osterbrock indicates that $R_{\mathrm{O}^{+2},2}$ should be $\sim 10\%$–20% larger than $R_{\mathrm{O}^{+2}}$ derived above, which is a negligible increase given the uncertainties in the nebular density. Note that He^+ (54.4 eV) and O^{+2} (54.9 eV) have nearly identical ionization potentials (Allen 1973, p. 37), so the He^+ and O^{+2} regions coincide.

A crude estimate of the mean density can be determined from the radio flux at 5 GHz and the Hβ flux. If the density is proportional to r^{-2}, the characteristic radius of an optically thick radio emission region is

$$R_\nu \approx 40(S_\nu/0.1\ \mathrm{mJy})^{1/2}(d/1\ \mathrm{kpc}) \times (\nu/1\ \mathrm{GHz})^{-1}(T_e/10^4\ \mathrm{K})^{-1/2}\ \mathrm{AU}\ , \quad (3)$$

where S_ν is the radio flux at frequency ν (Wright and Barlow 1975). The radius of a *constant density* H^+ region is

$$R_{\mathrm{H}^+} \approx 0.54(d/1\ \mathrm{kpc})^{2/3}(n_e^2/10^{18})^{-1/3}I_{4861}^{1/3}\ \mathrm{AU}\ , \quad (4)$$

where I_{4861} is the Hβ flux in units of 10^{-12} ergs cm^{-2} s^{-1} and T_e has been set to 20,000 K (Osterbrock 1974). If we require $R_{5\ \mathrm{GHz}} = R_{\mathrm{H}^+}$, then $R_{\mathrm{H}^+} \approx 15$ AU and $n_e \approx 2.5 \times 10^7$ cm^{-3} for $S_{5\ \mathrm{GHz}} \approx 0.4$ mJy (Seaquist, Taylor, and Button 1984). This result implies a mass-loss rate $\dot{M} \sim 7.5 \times 10^{-8}\ M_\odot$ yr^{-1} if the distance is 1 kpc, which is close to that expected for a typical M2 giant (Reimers 1981). An estimate of the optical depth in the radio is $\tau_{5\ \mathrm{GHz}} \approx 2.2 \times 10^{-14} n_{\mathrm{H}^+} n_e R_{\mathrm{H}^+} \approx 150$ (Osterbrock 1974; chap. 4) for the conditions derived above, but the assumption of $n \sim r^{-2}$ must be confirmed by radio observations at multiple frequencies.

The observed flux in the Balmer continuum provides additional support for $n_e = 2.5 \times 10^7$ cm^{-3} and $R_{\mathrm{H}^+} = 15$ AU. If all the flux at 1300 Å is provided by a hot star with $T_h \approx 70{,}000$ K, this component supplies $\sim 50\%$ of the flux at 2600 Å. The emission measure required to produce the remaining emission at 2600 Å by a nebula with $T_e = 20{,}000$ K is $n_e^2 V \approx 5 \times 10^{58}$ cm^{-3}, implying $n_e \sim 3 \times 10^7$ cm^{-3} for $R_{\mathrm{H}^+} \approx 15$ AU.

Finally, we can estimate the radius of the He^{+2} region from the intensity of the He II $\lambda 4686$ line. Assuming that the density in this zone is not smaller than the density in the O^{+2} zone, then $R_{\mathrm{He}^{+2}} \approx 3.0$–1.5 AU for $n_e = 1$–3×10^8 cm^{-3}, if He/H ≈ 0.1 and all of the helium is in the form of He^{+2}. Calculations discussed by Osterbrock (1974; p. 30) indicate that the density in the He^{+2} region should be significantly larger than that of the O^{+2} zone, so the radius of the He^{+2} zone is closer to 1–2 AU.

e) Reddening

KMH estimated a line-of-sight H I column density to RW Hya of $\sim 6.4 \times 10^{18}$ cm^{-2} from the Lyα absorption line, which corresponds to a color excess $E_{B-V} \approx 0.001$ (Savage and Mathis 1979). KW derived $E_{B-V} = 0.01 \pm 0.02$ from the depth of the 2200 Å absorption feature and fits to the ultraviolet continuum, and our analysis of the UV continuum suggests $E_{B-V} = 0.03 \pm 0.06$. The total extinction through the galaxy in the direction of RW Hya is $E_{B-V} \lesssim 0.03$ according to Burstein and Heiles (1982), so *the intrinsic interstellar extinction in the direction to RW Hya is close to zero.*

Additional reddening estimates can be obtained from our spectroscopic data. The Balmer decrement in 1985 June is consistent with case B recombination (Osterbrock 1974), and thus the Balmer lines are not obviously reddened unless the lower members of the series are optically thick (see Drake and Ulrich 1981). The decrement is far from case B in 1984 April, when Hα/H$\beta \approx 6$ and Hγ/H$\beta \approx 0.6$. These data suggest large optical depths or significant collisional excitation in the Balmer lines, which might be expected given the large electron density derived for the ionized nebula. The observed He I $\lambda 6678/\lambda 7065$ (~ 1) and He II $\lambda 1640/\lambda 4686$ (~ 4) intensity ratios are further evidence for collisional excitation or large optical depths, as these ratios are typically $\lambda 6678/\lambda 7065 \approx 2$ and $\lambda 1640/\lambda 4686 \approx 7$–8 in planetary nebulae (Robbins 1968; Osterbrock 1974, chap. 4; Seaton 1978).

These results suggest that the intensity ratios in the optical H I, He I, and He II lines have been modified from case B values, and it is useful to determine if collisional processes and optical depth effects should be important in RW Hya. The optical depth in Hα is $\tau_{\mathrm{H}\alpha} \approx 0.01(R/1\ \mathrm{AU})(n_e/10^7\ \mathrm{cm}^{-3}) \approx 0.5$ for the constant density case outlined above, providing there is no appreciable self-absorption in the Balmer lines (Cox and Mathews 1969). Calculations performed by Ferland and Netzer (1979) result in $\tau_{\mathrm{H}\alpha} \lesssim 5 \times 10^{-17} Q r^{-2}$, where Q is the number of H-ionizing photons and r is the separation between the ionizing source and the nebula. Taking $Q \approx 10^{45}$ s^{-1} and $r \approx 1$ AU, $\tau_{\mathrm{H}\alpha} \lesssim 100$. If the optical depth in Hα is large, the Hα/Hβ intensity ratio should approach 6 (Netzer 1975), which is the observed ratio in 1984 April. Additional observations are needed to verify that the Balmer decrement deviates from case B at all times in RW Hya, but it is clear that radiative transfer effects may be important at some epochs.

A final test for possible internal absorption may be obtained from the *IRAS* data (Kenyon, Fernandez-Castro, and Stence 1987). RW Hya possesses modest excesses at 12 μm and at 25 μm but unfortunately was not detected at 60 μm or 100 μm. The observed far-IR dust luminosity is $\sim 2(d/1\ \mathrm{kpc})^2\ L_\odot$, which is only 1% of the bolometric luminosity of the hot component. Thus, *there appears to be no indication of significant internal dust absorption in RW Hya*, and we may conclude that the observed $\lambda 1640/\lambda 4686$ flux ratio and the Balmer decrement have been affected by collisions and large optical depths.

IV. DISCUSSION

The results derived in the previous section, together with those described in other papers (KMH; KW; Slovak 1982), allow us to present a fairly clear picture of the RW Hya binary. Our analysis of this system is made easier by the very small extinction from interstellar *and* circumbinary material. Most other symbiotic stars have significant reddening ($E_{B-V} \gtrsim 0.2$), which complicates the interpretation of their far-UV data.

The cool component in RW Hya is an M2 giant, with $R_g \lesssim 100\ R_\odot$ and $L_g \lesssim 1700\ L_\odot$ ($M_{\mathrm{bol}} \gtrsim -3.3$). This star could be at the top of the giant branch or at the base of the asymptotic giant branch if it fills or nearly fills its tidal lobe and has a distance of ~ 1.5 kpc. If the distance is closer to ~ 1 kpc, $R_g \approx 70\ R_\odot$ and $L_g \approx 850\ L_\odot$ ($M_{\mathrm{bol}} \approx -2.5$); the cool star is then ascending the red giant branch for the first time. Additional data, such as a good orbit and a better estimate of the luminosity class, might enable us to discriminate between these possibilities. It is interesting to note that the mass-loss rate estimated from the radio flux at 5 GHz ($\sim 7.5 \times 10^{-8}\ M_\odot$ yr^{-1}) is close to the $\sim 2 \times 10^{-8}\ M_\odot$ yr^{-1} expected for an M giant with $R_g \approx 70\ R_\odot$ and $L_g \approx 850\ L_\odot$ using Reimers' (1981) mass-loss formula.

The ionized nebula in RW Hya possesses a gradient in the electron density, and is confined to the general vicinity of the binary. A dense ($n_e \approx 10^8$ cm^{-3}) He^{+2}, O^{+2} zone fills a volume which is comparable to the tidal volume of the hot component, with $R \approx 1$–3 AU. This region is surrounded by lower density material ($n_e \approx 2$–3×10^7 cm^{-3}) which is responsible for the H I emission lines and weak radio emission. The ionized mass of the H$^+$ region is $M_{\mathrm{H}^+} \approx 10^{-6}\ M_\odot$, and the nebula is replenished over a lifetime of $\tau_{\mathrm{H}^+} \approx M_{\mathrm{H}^+}/\dot{M} \approx 10$ yr, if $\dot{M} \approx 7$–$8 \times 10^{-8}\ M_\odot$ yr^{-1}. The wind velocity implied by the lifetime and size of the H$^+$ region is $v_{\mathrm{wind}} \approx 5$–10 km s^{-1}. Given the uncertainties involved in these estimates, the observed nebular properties are consistent with a low-velocity red giant wind ionized by radiation from the hot companion.

The hot component is similar to the central star of a planetary nebula, with $T_h \approx 70{,}000$–90,000 K, $R_h \approx 0.1\ R_\odot$, and $L_h \approx 200\ L_\odot$. Most of the continuum radiation produced by this object is emitted from 200 Å to 1000 Å, which is beyond the range of current satellite observatories. Spectra in this wavelength region are very important if we are to understand the energetics of binaries like RW Hya.

If the cool component in RW Hya does not fill its tidal lobe, the hot object must accrete material from the wind of the red giant. The accretion rate is roughly (Livio and Warner 1984):

$$\dot{M}_{\mathrm{acc}} \approx 5.5 \times 10^{-10} M^2 \dot{M}_g V_{\mathrm{rel}}^{-3} V_g^{-1} A^{-2}\ M_\odot\ \mathrm{yr}^{-1}\ , \quad (5)$$

where M is the mass of the accreting star in $M_\odot$, $\dot{M}_g$ is the mass-loss rate from the giant in units of $5 \times 10^{-7}\ M_\odot$ yr^{-1}, V_g is the velocity of this material in units of 20 km s^{-1}, and A is the binary separation in units of 10^{15} cm. The relative wind velocity, V_{rel}, is defined to be $(V_g^2 + V_0^2)^{1/2}$, where V_0 is the orbital velocity of the accreting star. Adopting a binary mass of $2\ M_\odot$, V_0 is ~ 35 km s^{-1} for a circular orbit. Since $V_g \approx 20$–30 km s^{-1} is typical for giants, V_{rel} is ~ 40 km s^{-1} and $\dot{M}_{\mathrm{acc}}$ is $\sim 10^{-8}\ M_\odot$ yr^{-1}. This results in an accretion luminosity of $\sim 5\ L_\odot$, which is not observable given the current state of the binary.

While there are significant uncertainties in equation (5), an accretion rate of $\sim 10^{-8}\ M_\odot$ yr^{-1} onto the hot component is physically significant during its expected lifetime. If *all* of the hot component's radiated luminosity is produced by hydrogen shell burning, the current rate of hydrogen consumption is $\dot{M}_{\mathrm{burn}} \approx 2 \times 10^{-9}\ M_\odot$ yr^{-1} (Iben 1982, and references therein). Since $\dot{M}_{\mathrm{acc}} > \dot{M}_{\mathrm{burn}}$, hydrogen accumulates at the surface of the hot component. This increase in envelope mass must eventually lead to a hydrogen shell flash (Iben 1982; Kenyon and Truran 1983; Paczyński and Żytkow 1978), when RW Hya will evolve into a *symbiotic nova* (Kenyon 1986, chaps. 4–5). Recurrence time scales for such events have been compiled by Iben (1982), who finds $\tau_{\mathrm{recur}} \approx 600$–700 yr if $\dot{M}_{\mathrm{acc}} \approx 10^{-8}\ M_\odot$ yr^{-1}. Thus, the 50 yr quiescent interval for RW Hya is not surprising, and we might expect a nova-like eruption sometime in the next millenium.

Several other well-studied symbiotic stars have optical/ultraviolet spectra which are dominated by strong permitted emission lines and rather weak intercombination or forbidden lines, as in RW Hya. The hot components in V443 Her and SY Mus were analyzed by KW, who found log $T_h = 4.90$, log $R_h/R_g = -2.7$, and log $L_h/L_g = -0.02$ for V443 Her, and log $T_h = 5.07$, log $R_h/R_g = -2.6$, and log $L_h = 0.09$ for SY Mus. The physical parameters derived for these binaries by Kenyon (1983; V443 Her) and Kenyon *et al.* (1985; SY Mus) are very similar to those derived for RW Hya, and neither V443 Her nor SY Mus has been recorded to have undergone an outburst in the past ~ 50 yr. These objects may also evolve into symbiotic novae once they have accreted enough material to initiate a thermonuclear runaway.

It is interesting to speculate how many presymbiotic novae are currently identified as symbiotic stars. Allen (1984) has presented spectra for nearly all known symbiotics, and ~ 20 have optical spectra which qualitatively resemble those of V443 Her, RW Hya, and SY Mus (strong H I, He I, and He II emission; weak [O III] lines; no [Fe VII] or λ6830 emission). It is difficult to estimate the total luminosity of the hot components in these binaries, since they are too faint or too heavily reddened to be observed with *IUE*. Nevertheless, the observed equivalent widths of He II λ4686 and Hβ suggest luminosities comparable to those derived for V443 Her, RW Hya, and SY Mus, providing the giant components are fairly normal.

If the ~ 20 symbiotics which resemble RW Hya and SY Mus do turn out to form a distinct subclass of symbiotic binaries, it appears that they can provide the observed rate of symbiotic nova eruptions. If the recurrence time scale for symbiotic novae is $\tau_{\mathrm{recur}} \sim 500$ yr (Iben 1982), then the expected rate of symbiotic nova eruptions is ~ 0.05 yr^{-1} assuming 25 dormant systems. The observed rate of 7 symbiotic novae in the past 50 yr (Kenyon 1986, chap. 5) is ~ 3 times the expected rate, which is surprisingly close given the admittedly large errors in estimating the recurrence time scale and the number of dormant symbiotic novae. It is encouraging that the observed rate of symbiotic novae can be understood if a small subclass of symbiotic stars undergo large nova-like eruptions every 500–1000 yr. Additional observations are clearly needed to establish a link between quiescent symbiotics and symbiotic novae, but such data could be important for understanding the eruptions of well-known symbiotic novae like AG Peg and RR Tel.

V. SUMMARY

We have presented contemporaneous ultraviolet/optical spectrophotometry and infrared photometery for the symbiotic binary RW Hya. Our major conclusions may be summarized as follows.

1. The cool component is an M2 giant with $L \approx 1000\ L_\odot$. It has a mass-loss rate of ~ 5–$10 \times 10^{-8}\ M_\odot$ yr^{-1} if the radio spectrum is consistent with $S_\nu \approx \nu^{0.6}$.

2. The hot component is similar to the central star of a planetary nebula, with $T_h \approx 70{,}000$–90,000 K and $L \approx 200\ L_\odot$. This compact star accretes material from the wind of the red giant companion at a rate of $\sim 10^{-8}\ M_\odot$ yr^{-1}, producing an accretion luminosity of $\sim 5\ L_\odot$. Direct accretion of material is not an important energy source in RW Hya, but accretion is vital for the continued support of the hydrogen-burning shell which provides the bolometric luminosity of the hot object.

3. The nebula in RW Hya has an observable density gradient, with $n_e \gtrsim 3 \times 10^8$ cm^{-3} in the He^{+2} and O^{+2} zones, and $\langle n_e \rangle \approx 2$–$3 \times 10^7$ cm^{-3} in the H$^+$ region. The H$^+$ region in RW Hya surrounds the entire binary system, but the He^{+2} region is confined to the immediate vicinity of the hot component.

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