THE ASTROPHYSICAL JOURNAL, 331:477–485, 1988 August 1

THE C IV DOUBLET RATIO INTENSITY EFFECT IN SYMBIOTIC STARS

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Received 1987 November 4; accepted 1988 January 22

ABSTRACT

The first successful high-resolution ultraviolet spectra in the λλ1200–2000 wavelength range of the symbiotic variable R Aquarii and its nebular jet were obtained in 1987 July with the *International Ultraviolet Explorer* (*IUE*). The line profile structure of the C IV λλ1548, 1550 doublet in the jet indicates multicomponent velocity structure from an optically thin emitting gas. The C IV doublet profiles in the compact H II region engulfing the Mira and hot companion binary also suggest multicomponent structure, in which the radial velocities range up to ~ -100 km s^{-1}. The value of the doublet intensity ratio in the R Aqr H II region is $I(\lambda 1548)/I(\lambda 1550) \sim 0.6$, which is less than the optically thick limit of unity, an effect which has also been observed in other similar symbiotic stars such as RX Pup. In the case of RX Pup, however, the C IV doublet intensity ratio was $I(\lambda 1548)/I(\lambda 1550) \sim 0.6$ during an enhanced phase of UV and optical emission, but became larger, acquiring a value ~ 1, as the star declined in light over a 5 yr period. The anomalous behavior of the C IV doublet intensities, which we refer to as the "C IV Doublet Ratio Intensity Effect," may provide an important tool for studying the spatial structure and temporal nature of winds in symbiotic stars.

Subject headings: stars: binaries — stars: emission-line — stars: individual — stars: winds — ultraviolet: spectra

I. INTRODUCTION

Symbiotic stars are thought to be interacting binaries with a red giant or Mira variable and a hot companion. These objects have been the subject of many recent investigations, but a number of important properties of these systems remain obscure. Low-velocity winds from the late-type giant in symbiotics are believed to provide circumstellar material, which is photoionized by the intense radiation field of a luminous white dwarf or main–sequence-type star, and perhaps by an accretion disk. There is growing evidence, however, for the presence of high-velocity winds in these systems, which are probably associated with mass expulsion from regions near the hot component. For example, very broad emission lines and P Cygni profiles have been observed in AG Peg that suggest velocities of 900 km s^{-1} (Penston and Allen 1985). Broad emission has been observed in other symbiotic nova such as V1329 Cyg (Crampton *et al.* 1970) and RR Tel (Penston *et al.* 1983; Ponz, Cassatella, and Viotti 1982). The classical symbiotic AG Dra exhibits a low-velocity (-170 km s^{-1}) P Cygni profile structure in the high-ionization N V doublet, which is absent in C IV (Viotti *et al.* 1983). In this star, the strong He II line presents broad wings. It is however difficult, on the basis of these observations, to clarify the nature of the winds in these systems.

Recently, Kafatos, Michalitsianos, and Fahey (1985) from 5 yr of *IUE* observations of the Mira-type symbiotic RX Pup found that at maximum luminosity the intensity ratio of the C IV resonance doublet is smaller than the optically thick limit of unity, which could imply the presence of a high-velocity wind of 600 to 700 km s^{-1}. Similar C IV doublet ratios observed from the first successful HIRES IUE-SWP λλ1200–2000 spectra ($\Delta\lambda \sim 0.1$ Å resolution) of R Aqr can also be interpreted as evidence for a high-velocity wind in this system. A wind velocity of $\sim$600–700 km s^{-1} in R Aqr would be a factor ~ 3 greater compared with the largest velocities seen in the star and the surrounding filamentary nebula and jet (cf. Solf and Ulrich 1985). In this paper we shall describe these new results for R Aqr in context with previously obtained HIRES-SWP spectra of RX Pup, in which we propose that the C IV doublet ratio can provide an important diagnostic tool for studying winds in symbiotic stars.

R Aqr is especially interesting because of its radio/optical/UV jet, which is embedded in a NS-oriented bipolar $\sim 1'$ nebula. The spatial extent of radio/optical jet that is 6''.5 – NE from the star has enabled us to obtain *IUE* HIRES and low-resolution SWP (LORES $\Delta\lambda \sim 6$ Å resolution) spectra of the jet, and the compact H II region which surrounds the Mira/hot

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companion. These spectra were acquired in a collaborative NASA/ESA (Vilspa) program.

The general properties of the *IUE* HIRES-SWP spectra obtained of the jet and H II region of R Aqr will be described elsewhere. Here, we will focus on the C IV $\lambda\lambda$1548,1550 doublet. The general properties of R Aqr and its radio/optical/UV jet have been described extensively (cf. Kafatos and Michalitsianos 1982; Michalitsianos 1984; Kafatos, Michalitsianos, and Hollis 1986; Solf and Ulrich 1985). The radio properties of the jet and H II region are given by Kafatos, Hollis, and Michalitsianos (1983) and Hollis *et al.* (1985, 1986*a*). Our *IUE* observations of R Aqr and RX Pup and method of data analysis follow.

II. OBSERVATIONS

IUE-HIRES observations were acquired exclusively in the large 10 × 20″ entrance aperture. SWP 29543 of the jet was obtained on 1986 October 27 in 675 minutes integration. The *IUE* entrance slit was offset from the central star by ~6″ – NE relative to the star using the radio coordinates from 6 cm VLA maps, in a manner used to obtain earlier low-resolution *IUE* spectra of the jet (Kafatos, Michalitsianos, and Hollis 1986). While centering on radio jet feature B at $\alpha(1950.0) = 23^h41^m14^s.5$ and $\delta(1950.0) = -15°33'36''$ (see Fig. 1 of Kafatos, Michalitsianos, and Hollis 1986), the small axis of the large aperture was oriented at a position angle p.a. = 35° (rotating east from 0° north), which placed R Aqr ~2″ beyond the edge of the slit. Thus the axis defined by the extended structure of the jet was nearly perpendicular to the spectral dispersion. SWP 31102 of the H II region was obtained on 1987 June 4 in 770 minutes integration, where p.a. = 47°. The aperture was centered on the R Aqr-H II region at $\alpha(1950.0) = 23^h41^m14^s.3$ and $\delta(1950.0) = 15°33'42''.8$. These IUE-HIRES spectra of R Aqr are compared with a HIRES (SWP 16597) exposure of RX Pup, obtained on 1982 March 22 in 300 minutes.

The line profiles of C IV $\lambda\lambda$1548, 1550 shown in Figures 1 and 2 have been smoothed with a 5-point running average to remove high-frequency noise. The background noise in the vicinity of the doublet in SWP 29543 was ~160 DN, with the peak emission of the λ1548 line achieving ~220 DN, or ~60 DN above background. Continuum emission has not been detected in any order. The λ1550 doublet component in SWP 29543 was approximately 30 to 40 DN above background, and is clearly weaker compared with λ1548 in *IUE* photowrites. We estimate C IV $I(\lambda1548)/I(\lambda1550) \sim 2$ in the nebular jet.

The C IV doublet in the H II region SWP 31102 was ~215 DN, or ~115 DN above background. Two pixels in the λ1550 line were affected by radiation "hits." However, because a single data point in the *IUE* extraction algorithms represents an average of 9 pixels, a running average over five data points is effective at removing the spurious flux from single pixel values that are unusually high compared with adjacent pixels.

Similarly, we have applied the 5-point running average to the C IV doublet profiles of RX Pup (SWP 16597) for comparison with R Aqr. Each C IV doublet is composed of at least two or three sharp emission components that are separated by $\Delta v \sim 40$ km s^{-1} (cf. Kafatos, Hollis, and Michalitsianos 1983; Kafatos, Michalitsianos, and Hollis 1985). P Cygni-like structure is suspected in both lines. The C IV doublet ratio is

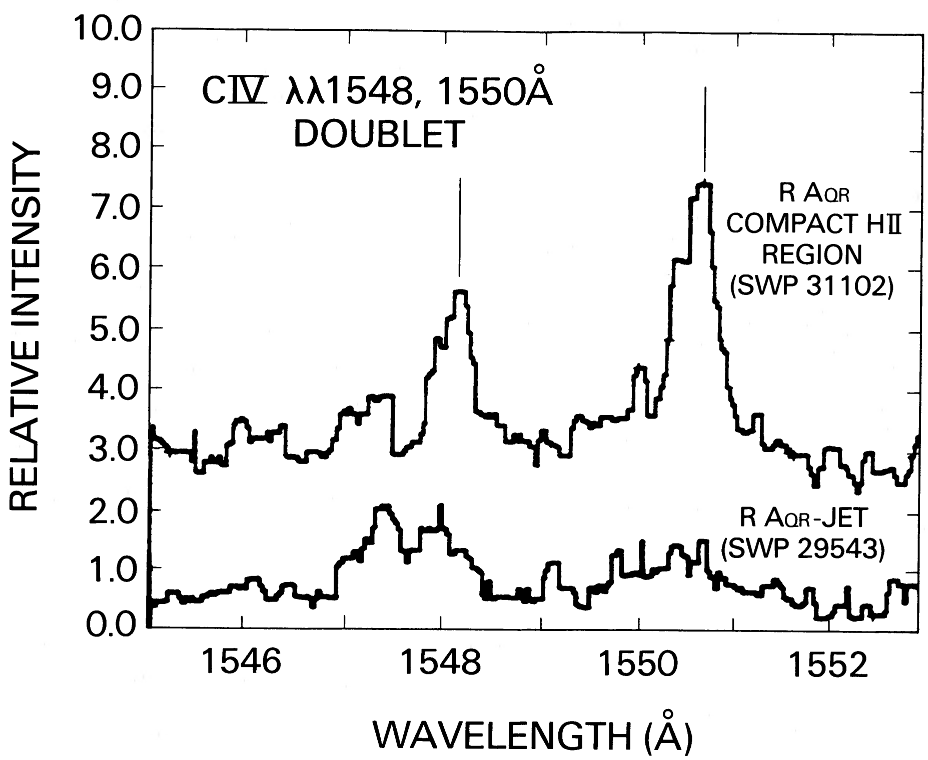

FIG. 1.—The C IV doublet in R Aqr H II region (*upper curve*) and the jet (*lower curve*). The profiles were smoothed with a 5-point running average to remove high-frequency noise. The λ1550 component in the jet is weak by a factor ~2 compared with λ1548. The λ1548 profile in the jet has a central absorption reversal, which is evident in *IUE* photowrite. The doublet profiles of the jet appear displaced $\Delta\lambda \sim 0.8$ Å relative to the H II region spectrum. We attribute this to the primary UV source not being centered in the large aperture. The vertical lines indicate the rest wavelength after correcting for radial velocity of the star ($V_R = -23$ km s^{-1}).

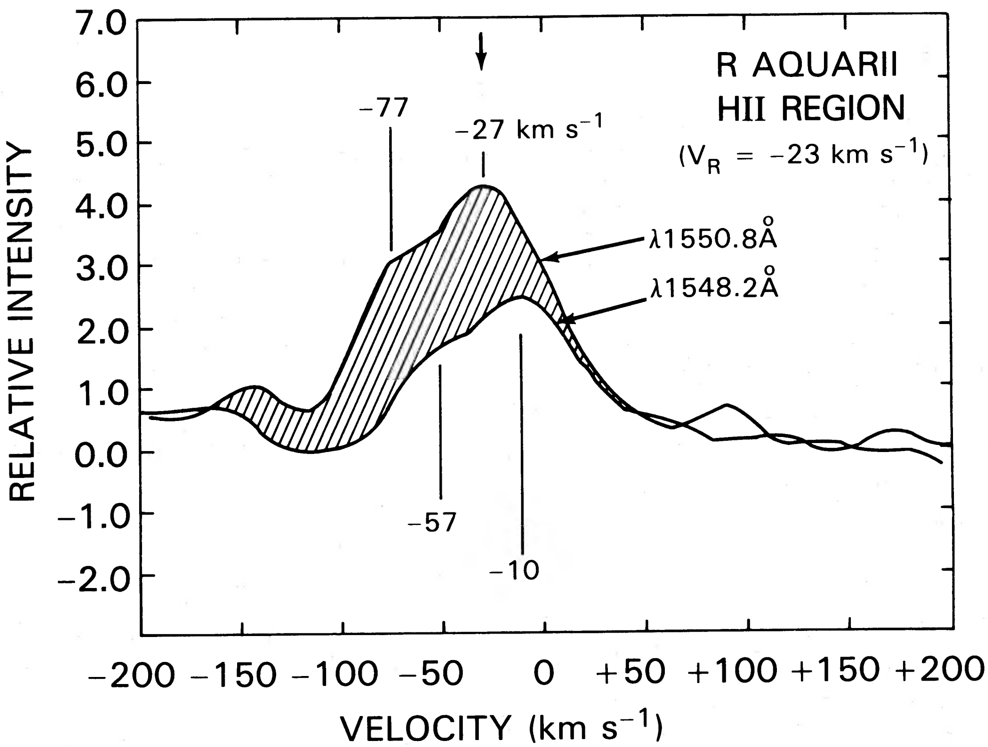

FIG. 2.—The C IV red and blue doublet lines of the R Aqr H II region are overplotted in velocity space, after applying a 5-point smoothing. Double Gaussian fits were applied to each profile to determine the velocity centers. The velocities shown are from best fit and are not corrected for stellar radial velocity (*arrow*); therefore, +0 km s^{-1} corresponds to the laboratory rest wavelength. The estimated error on the Gaussian fits was ±0.5 km s^{-1}. The velocity resolution for well-exposed emission features in SWP-HIRES *IUE* spectra is ~ ±2.0 km s^{-1} at λ1550. The shaded area indicates the region in velocity space over which $I(\lambda1548)/I(\lambda1550) < 1$.

$I(\lambda1548)/I(\lambda1550) \sim 0.6$. The I_B/I_R is estimated from the fact that I_λ was measured using an interactive "sum of ordinates" integration, which was repeatable to ~2%–3%. The flux profiles consisted of about 45 data points each, and had been subjected to a 5-point running average low-pass filter in all cases. The observations were obtained when RX Pup was near maximum emission, during a phase of UV flux brightening around 1982 (Kafatos, Michalitsianos, and Fahey 1985). Most of the narrow emission components that combine to form the broadened profile are redshifted with respect to the velocity of the star ($V_R \sim +11 \pm 2.5$ km s^{-1}, Wallerstein 1986).

III. DISCUSSION AND ANALYSIS

The λ1548.2 doublet profile of jet feature B (Fig. 1; SWP 29543) exhibits two emission components that are separated by $\Delta\lambda \sim 0.6$ Å or ~100 km s^{-1}, and/or a narrow blueward displaced absorption feature. The full base width of the λ1548.2 line is less than 200 km s^{-1}. Emission structure within the core of the λ1550 line cannot be discerned, because it is weaker by a factor of ~2, consistent with optically thin photoexcited region. Electron densities and temperatures of jet feature B have been estimated to be $n_e \gtrsim 10^4$ cm^{-3} and $T_e \sim 20{,}000$ K, respectively (cf. Kafatos, Michalitsianos, and Hollis 1986). The doublet appears blueward displaced relative to the rest wavelength by $\Delta\lambda \lesssim 0.8$ Å. Because radial velocities associated with feature B from optical nebular lines are small, less than 100 km s^{-1} (Solf and Ulrich 1985), this wavelength displacement is probably the result of the peak UV source being offset relative to the peak 6 cm radio flux of feature B, because VLA maps were used to position the large *IUE* entrance aperture on the H II region and extended radio jet structure.

Both λλ1548, 1550 lines were detected in the central H II region, where n_e[H II region] $\gtrsim 10^6$ cm^{-3} is greater, and T_e[H II region] ~ 15,000 K is smaller, compared with the jet feature B (Kafatos, Michalitsianos, and Hollis 1986). Two narrow emission components were detected in both lines. Peak emission in the line profile occurs near the rest wavelength for both members of the doublet, while a weaker peak is blueward displaced. We have also overplotted the λ1550.8 line and λ1548.2 lines of the H II region in Figure 2, in order to compare the line profile structure in velocity space. Gaussian multiple profiles were fitted to the profiles at λλ1548.2 and 1550.8 to determine the wavelength separation of the individual emission components. High-frequency noise was reduced by a 5-point running average which acts as a digital low-pass filter. The formal fit errors of velocity are ±0.5 km s^{-1}; the instrument velocity resolution at λ1550 is ~ ±2.0 km s^{-1} for well-exposed narrow emission lines. The peak emission for both λλ1548.2, 1550.8 lines is consistent with the measured radial velocity $V_R \sim -23$ km s^{-1} of the star, while a blueward displaced component of $\Delta v \sim -50$ km s^{-1} relative to the star is indicated in both lines. After smoothing, both red and blue lines exhibit P Cygni structure that suggests a wind component of ~100 km s^{-1}.

In Figure 2, the shaded area formed by the superposition of the line profiles extends to ~ −150 km s^{-1}, and clearly shows velocity range over which the doublet intensity ratio $I(\lambda1548)/I(\lambda1550)$ is less than unity in the H II region. The presence of at least two narrow emission components in the doublet complicates any attempt at deconvolution. However, the line profile structure of both red and blue doublet members appears similar overall, while the λ1548.2 flux is generally weaker compared with $\lambda1550$. Accordingly, at a given wavelength in the wing and core of the line profile, broad C IV P Cygni structure appropriate to a high-velocity wind of 600 to 700 km s^{-1} could superpose its absorption on narrow emission-line–forming regions, which move with differential velocities. This would produce a general diminution of flux at $\lambda1548.2$ compared with $\lambda1550.8$.

Radiative transfer effects, however, are complex, and require a complete analysis under multiscattering conditions. Olson (1982) has considered the effects which spherically symmetric winds can have on closely spaced resonance doublet profiles in context with O and B-type stellar winds, when $v_{\rm wind}$ is comparable to, or exceeds the velocity separation of the doublet. In such cases, the source function of the longer wavelength member of the doublet $S_{\nu,R}$ depends on nonlocal values of the short wavelength source function $S_{\nu,B}$. Radiation scattered in our line of sight by the blue line can be scattered again by the red line, enhancing emission in the red wing of $\lambda1550.8$ line (cf. Castor and Lamers 1979).

The presence of narrow emission components in the line profile, which are separated in velocity space by $\sim$40 to 50 km s^{-1}, and suspected P Cygni structure which may be caused by a wind speed of more than 600 km s^{-1} associated with the doublet intensity ratio of $I(\lambda1548)/I(\lambda1550) < 1$, are also characteristic the C IV lines in RX Pup (Kafatos, Michalitsianos 1986), and suggests similar structure of the C IV forming regions in these systems. RX Pup is similar to R Aqr in a number of other respects: (i) it is associated with thermal-dust emission, (ii) it contains a Mira (580^d period) (Whitelock *et al.* 1983), and (iii) it is a prominent radio continuum source (Seaquist 1977; Hollis *et al.* 1986*b*). Sometime between 1982 June 11 and 1982 March 22 (Fig. 3), the C IV flux increased in RX Pup by $\sim$30%, while other resonance lines such as He II and Mg II exhibited greater variations, that ranged up to $\sim$80% (Kafatos, Michalitsianos, and Fahey 1985). In Figure 3, the center of the C IV profiles is longward of the rest wavelength, similar to the redward shifted of C IV and Mg II $\lambda\lambda2795$, 2802 reported by Mueller and Nussbaumer (1985) in HM Sge. Kafatos, Michalitsianos, and Fahey (1985) suggested that the narrow emission component structure of the C IV lines is attributed to a system of hot ionized rings which encircle the hot companion in Keplerian orbits.

In Figure 4, we applied Gaussian fits to the 5-point smoothed C IV profiles of RX Pup. Note that the doublet intensity ratio is less than one over a velocity range up to ~ -200 km s^{-1} (correcting for stellar motion of $+11$ km s^{-1}). In R Aqr (H II region), C IV $I(\lambda1548)/I(\lambda1550)$ is less than unity over a similar velocity range up to $\sim +200$ km s^{-1}, but which is predominantly blueward of the rest wavelength (after correcting for $V_R \sim +23$ km s^{-1}). For the $\lambda1550.8$ line, the average velocity separation indicates an interval between successive peaks of $\overline{\Delta V} \sim 40$ km s^{-1}, while for the $\lambda1550.8$ line the average interval is $\overline{\Delta V} \sim 80$ km s^{-1}, if the redward most emission peak at $+124$ km s^{-1} is included in the triple Gaussian fit. In fact, the $\lambda1550.8$ line of RX Pup produced the largest residuals compared with the $\lambda1548.2$ line. The largest residuals could be explained if a fourth weak emission component of intermediate velocity (between $+50$ and $+124$ km s^{-1}) is present. The average velocity interval of 39 km s^{-1} found in the C IV $\lambda1548.2$ line of RX Pup is strikingly similar to the

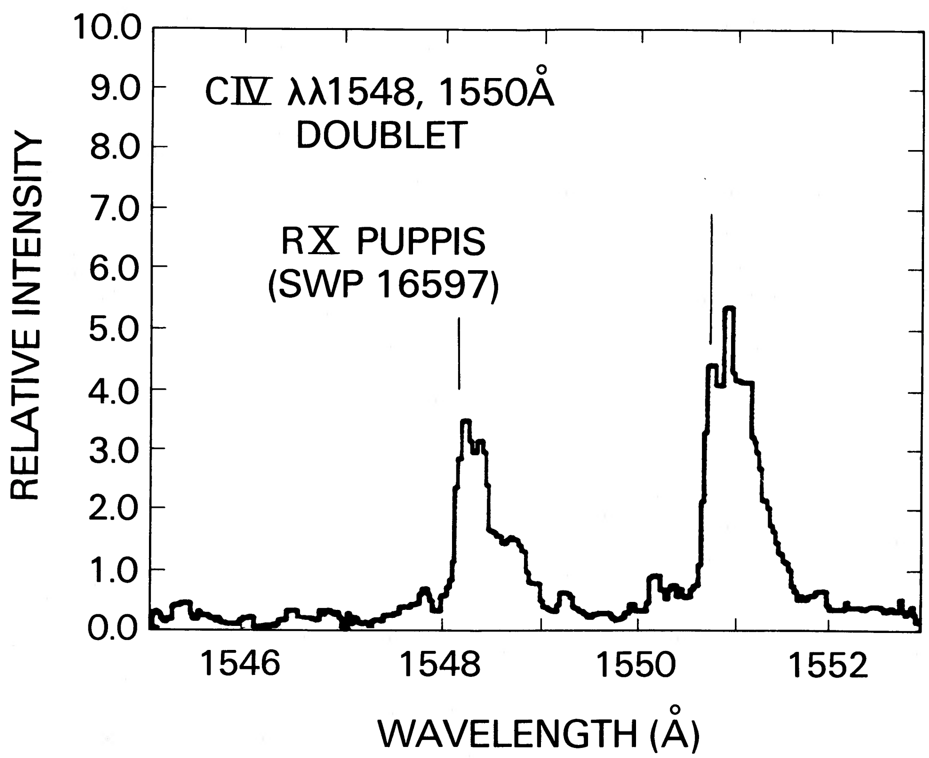

FIG. 3.—The C IV doublet in RX Pup (HIRES-SWP 16957; 1982 March 22) during a brightening phase of UV line emission. Smoothing using a 5-point running average was applied to the profiles for comparison with R Aqr. Vertical lines indicate the radial velocity of the star of $V_R \sim +11$ km s^{-1}. P Cygni structure is suggested in both doublet members, although the exposure was not sufficiently long to detect continuum. The profiles indicate a narrow P Cygni absorption dip in the blue wing that corresponds to a wind speed of ~ -90 km s^{-1}.

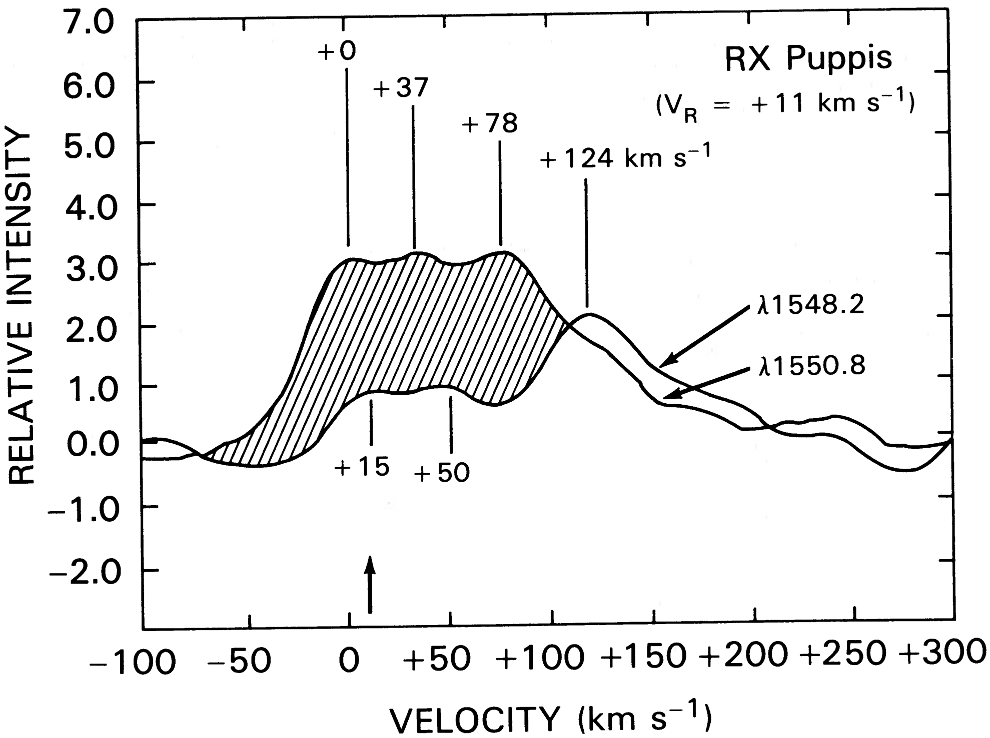

FIG. 4.—The C IV doublet members have been overplotted in velocity space with 5-point smoothing. A three-Gaussian fit was applied to each doublet member, and the velocities shown correspond to best fit, but are not corrected for the stellar velocity (*vertical arrow*). The shaded area indicates the region in velocity space over which $I(\lambda1548)/I(\lambda1550) < 1$.

velocity structure which characterizes the line profiles of the C IV doublet in the R Aqr H II region, and suggests the ionized C IV emitting regions in these systems have common structure.

Previously, Kafatos, Michalitsianos, and Fahey (1985) have found an inverse correlation between the C IV integrated line flux $I(\lambda1548)+I(\lambda1550)$ and the $I(\lambda1548)/I(\lambda1550)$ ratio in RX Pup, where the ratio decreases with increasing absolute line intensity. In Figure 5, we show this correlation, but have included the most recent data points obtained with *IUE*. We refer to this behavior as the "doublet ratio-intensity effect." Here, we have found another similar relationship between the C IV doublet ratio and the *V* magnitude for RX Pup. The visual magnitude of RX Pup from the *IUE* Fine Error Sensor (FES) has been plotted against the C IV $I(\lambda1548)/I(\lambda1550)$ ratio in Figure 6, from HIRES-SWP data which spans 1980 September 20 to 1984 March 22 (Kafatos, Mitchalitsianos, and Fahey *et al.* 1985). We include additional observations of 1986 May 8 and 1987 July 2 from our most recent unpublished HIRES-SWP spectra. In Figure 6, both the FES counts (*lower panel*) and the calculated *V* magnitudes using a constant $(B-V) = 1.2$ (Whitelock *et al.* 1983, 1984) (*upper panel*) are shown, after using an *IUE* FES sensitivity correction (cf. Imhoff and Wasatonic 1986).

Compared with the *V* magnitude obtained by Whitelock *et al.* (1984) of $V = 10.7$ in 1982 and $V = 11.0$ in 1983, the *IUE* FES values are systematically greater by ~0.4 mag. This discrepancy could be due to the broader spectral response of ±1000 Å of the FES-monitor, where the peak sensitivity is λ5400, but is unblocked to extreme blue and red colors. Accordingly, in cases where the UV source and cool star make contributions to the integrated light, the *IUE* magnitudes probably reflect the broad wavelength contributions of both hot and cool sources. Estimates of $(B-V)$ were not available during our *IUE* observations, and relative variations of *B* and *V* could introduce uncertainties in visual magnitude. However, FES counts do provide a self-consistent check for the decline in overall light from the system between 1980 and 1987.

For the reasons stated above, the decline of *IUE* FES *V* mag over ~5 yr cannot easily be attributed to variations of either the hot or cool components of the system. The decline in *V* and *J* between 1982 and 1983 has been attributed to obscuration of the Mira and hot continuum source by a dust cloud (Whitelock *et al.* 1984), although the strengthening of nebular lines during this period is not readily explained by their model. Whitelock *et al.* (1984) suspect that the complex variations of emission-line strengths and continuum intensity observed in the system could be attributed to orbital motion. However, because $I(\lambda1548)/I(\lambda1550)$ is inversely correlated with the C IV line intensity, as well as with the visual light, we suspect the decline in visual light between 1982 to 1987 in RX Pup is probably associated with variations in the UV source of the system.

If the "doublet ratio intensity" effect is due to a wind, a minimum wind speed of ~600 to 700 km s^{-1} is required, because the P Cygni absorption trough must extend at least −500 km s^{-1} for the doublet separation, plus an additional ~−100 to −200 km s^{-1} to cover the blue wing of the broadened λ1548 profile. However, the 300 minute exposure (Fig. 2) of RX Pup was not sufficiently long to detect the continuum in the vicinity of C IV, which would have enabled us to confirm the presence of P Cygni structure. UV continuum flux was not detected in our ~15 hr integrations with *IUE* SWP-HIRES mode, which may be explained by the fact that there was a further decline in visual light between 1986 and 1987.

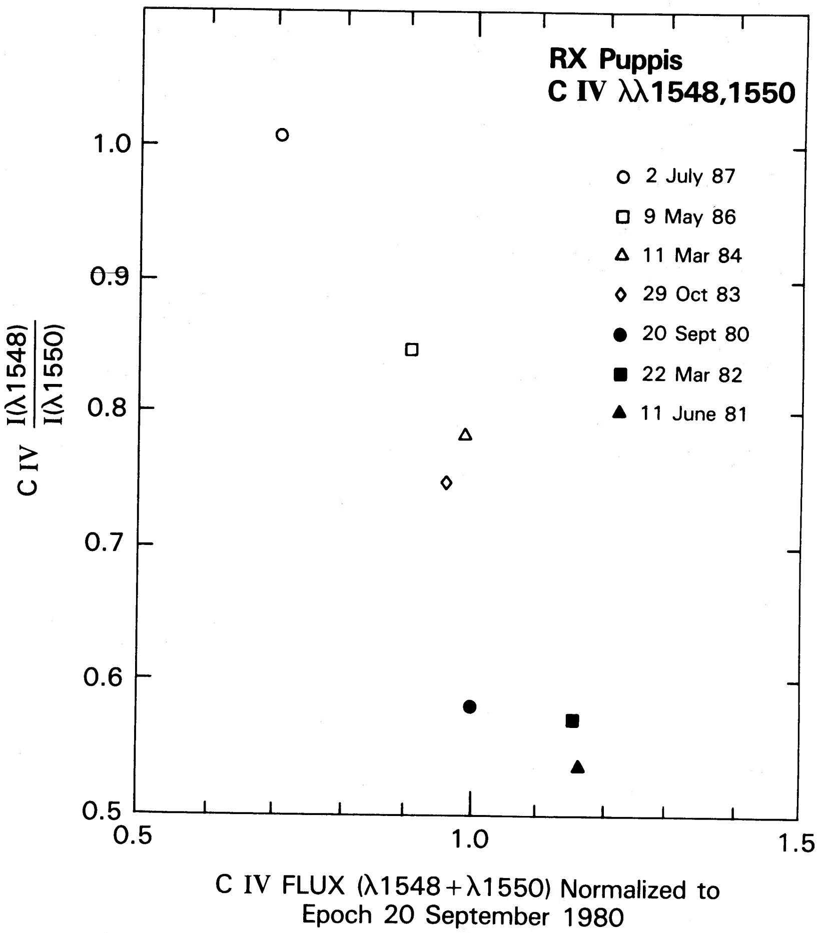

FIG. 5.—The C IV doublet intensity ratio $I(\lambda1548)/I(\lambda1550)$ plotted against the combined doublet intensities for RX Pup, for which the C IV fluxes are normalized to epoch 1987 September 20. The key indicates the date of observation. The plot indicates a nearly linear trend over the range $0.5 \lesssim I(\lambda1548)/I(\lambda1550) \lesssim 1$. The most recent IUE-HIRES SWP spectra of RX Pup obtained on 1987 July 2 indicates the doublet ratio is approximately unity.

For example, our most recent exposure of 14.6 hr on 1987 July 2 did not detect the UV continuum in the SWP range.

Similarly, UV continuum was not detected in the SWP range in either the H II region or the R Aqr jet. However, if a high speed wind also explains the anomalous C IV doublet ratio of $I(\lambda1548)/I(\lambda1550) \gtrsim 0.6$ in the R Aqr H II region, the wind velocity would exceed the largest radial velocities observed in optical nebular lines by a factor of $\sim$4 to 5 (cf. Wallerstein and Greenstein 1980). High-resolution optical echelle spectra of nebular lines indicate that maximum expansion velocities in the inner NS nebula are less than ~ -200 km s^{-1} (Solf and Ulrich 1985). Evidence for high-velocity motion of $\sim$700 km s^{-1} are not indicated in any of the intercombination lines such as O III] λλ1660, 1666, Si III] λλ1882, 1892, and C III] λλ1906, 1909.

However, a high speed wind could still be present because the ionization temperatures characteristic of C IV formation are $T \sim 50{,}000$ to 100,000 K. Accordingly, a high-velocity wind may only be detectable in high-excitation resonance lines of C IV and N V λλ1238, 1242 in HIRES-SWP spectra. Note that N V is only seen in LORES *IUE* spectra of the jet features, but is *not* observed in LORES or HIRES spectra of the R Aqr H II region (Kafatos, Michalitsianos, and Hollis 1986). Accordingly, the *only* manifestation of a high-velocity material in R Aqr may be the anomalous C IV doublet intensity ratios, if this interpretation is correct. Moreover, if a high-speed wind is present, the curious absence of P Cygni structure in C IV in LORES-IUE ($\Delta\lambda = 6$ Å resolution) spectra in both the R Aqr H II region and RX Pup, places strong upper limits on $v_{\rm wind}$ for both stars of $\sim$1000 km s^{-1}. For example, $\sim$1000 km s^{-1} P Cygni wind profiles are resolved in LORES-SWP spectra of planetary nebula IC 418 (cf. Harrington *et al.* 1980; Flower 1983). Accordingly, a narrow range of wind velocities of $700 \lesssim v_{\rm wind} \lesssim 1000$ km s^{-1} places tight constraints on the wind speed, which follows from our arguments concerning the C IV doublet intensity ratios of RX Pup and R Aqr-H II region, and the absence of P Cygni structure in LORES-SWP spectra in both stars. Similar arguments would also apply to Z And during outburst (Cassatella 1988). CH Cyg (Selvelli 1988) and AG Peg (Chochol, Komarek, and Vittone 1988) also exhibit anomalous C IV doublet intensities, but C IV P Cygni wind profiles in the LORES IUE spectra are not evident.

Escape velocities in the 700 to 1000 km s^{-1} range correspond to stellar radii of $R/R_\odot \sim 0.8$ to 0.4, respectively, if $M \sim 1\ M_\odot$; this is appropriate to central stars of planetary nebulae. A hot star with surface temperatures in temperatures in excess of 50,000 K would be radiating at least 3×10^3 $L_\odot$–900 $L_\odot$, respectively, which is sufficient to provide the observed ionization in R Aqr and RX Pup. Alternatively, the ionizing radiation could be coming from the hot inner regions

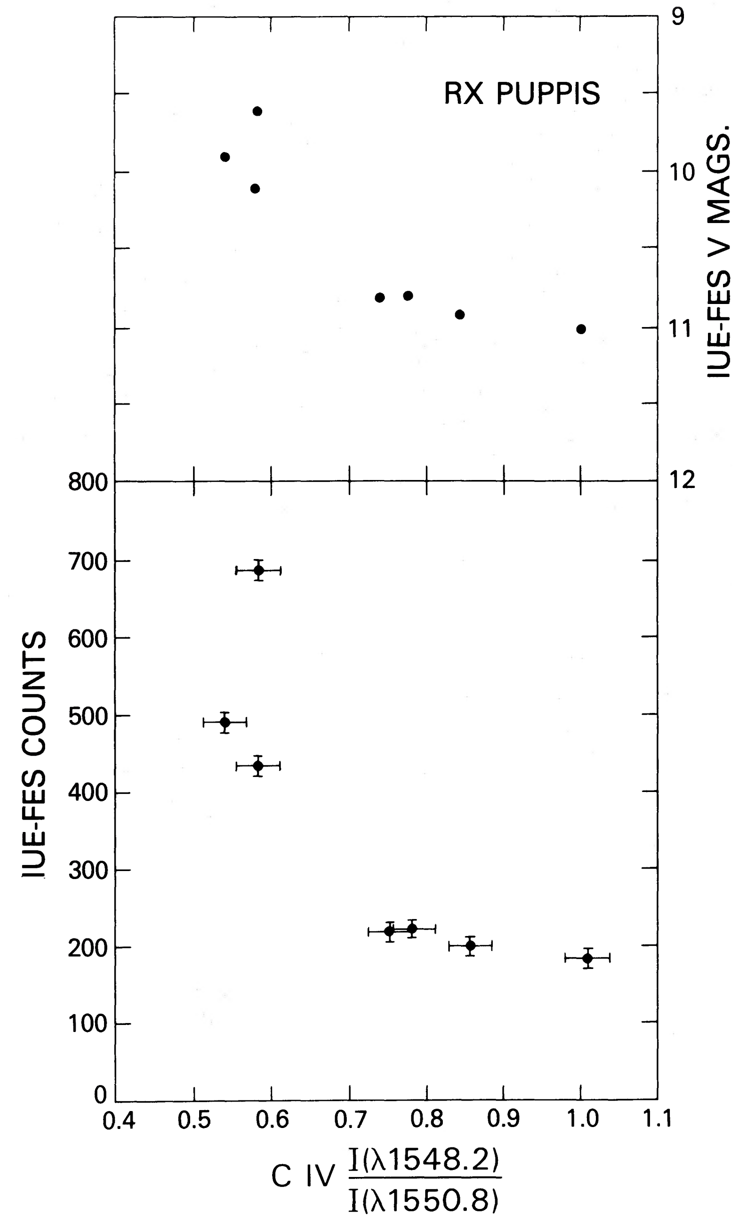

FIG. 6.—Absolute *IUE* FES counts (*lower panel*) and the corresponding FES *V* mag (*upper panel*) of RX Pup obtained between 1987 September 20 and 1987 July 2. The *V* mag is computed using the sensitivity correction of Imhoff and Wasatonic (1986). A constant $(B-V) = 1.2$ is assumed to obtain the color and *V* mag. The C IV relative line fluxes are obtained after a 5-point running average to eliminate noise and particle radiation "hits." The relative fluxes are measured over a specified wavelength $\Delta\lambda$ range for each doublet; for the λ1548.2 line, $\Delta\lambda = \lambda\lambda$1547.4 to 1550.0 Å, and for λ1550.8, $\Delta\lambda = \lambda\lambda$1550.2 to 1551.8 Å.

of the accretion disk with effective photospheric sizes of a fraction of a solar radius.

The mass-loss rate in a hot stellar wind can be estimated from Olson (1982) and Cordova and Mason (1982). The relevant equation for C IV is:

$$N[\text{C IV}]/N[\text{C}]\dot{M} = 6 \times 10^{-12}(R_*/R_\odot)(V_\infty/1000)^2 T_B \times (\text{C IV})(1+\gamma)0.5^\gamma \,. \quad (1)$$

The quantity T_B (cf. Olson 1982) corresponds to the blue doublet component and is related to the optical depth. We estimate that T_B is probably ~ 5; if T_B were greater, say ~ 20, then the λ1548 line would be completely absent. We do not have a reliable way to estimate the optical depth because of the complex geometry of the system, in which contributions from streamers or rings (Kafatos, Michalitsianos, and Fahey 1985) could be significant. In addition, we need to compute the ionic abundance N[C IV]/N[C]. This is estimated from Kafatos, Michalitsianos, and Feibelman (1982) for RX Pup, where N[C IV]/N[C] ~ 0.38; and from Kafatos, Michalitsianos, and Hollis (1986) for R Aqr N[C IV]/N[C] ~ 0.28. The radius of the hot star, or alternatively the inner region of the accretion disk where the wind could originate, is in the range $6 \times 10^{-3} \lesssim R_*/R_\odot \lesssim 9 \times 10^{-2}$ for R Aqr, and $R_*/R_\odot \sim 0.14$ for RX Pup (Kafatos, Michalitsianos, and Fahey 1985; Kafatos, Michalitsianos, and Hollis 1986). We prefer the higher values for R Aqr, because the maximum speed v_∞, allowed from the lack of an observable P Cygni profile in LORES SWP spectra is ~ 1000 km s^{-1}; this corresponds to $R_*/R_\odot \sim 0.4$. Using equation (1), we then find that the *hot* wind which we suspect is present from the C IV doublet ratio has a mass-loss rate (i) R Aqr: $4.5 \times 10^{-12} \lesssim \dot{M}_h \lesssim 10^{-11}\ M_\odot$ yr^{-1}, and similarly (ii) RX Pup: $1.5 \times 10^{-11} \lesssim \dot{M}_n \lesssim 3.1 \times 10^{-11}\ M_\odot$ yr^{-1}. These limits should be reduced by $\sim \frac{1}{2}$ if the escaping wind emanates above and below a thick accretion disk with an opening angle $\gtrsim 100°$.

These values for R Aqr are much smaller compared with the cool wind if it originates in the outer regions of a thick accretion disk, for which $\dot{M}_C \sim 2 \times 10^{-8}\ M_\odot$ yr^{-1} (Kafatos, Michalitsianos, and Hollis 1986). The momentum of the cool wind is proportional to $\dot{M}_C v_C$, where $v_C \sim 100$ km s^{-1}, which would be much larger than the momentum of the hot wind, which is proportional to $\dot{M} v_h$, by at least a factor of ~ 200. The hot wind in both systems is, therefore, evident in HIRES profiles of C IV only. The RX Pup H II region is much more highly ionized compared with the R Aqr central H II region. Accordingly, the hot star wind in RX Pup is probably more dominant compared with R Aqr. Thus, the R Aqr wind is dominated by the cool wind which emanates from the Mira or from the outer regions of an extended accretion disk that encircles the hot companion (Kafatos, Michalitsianos, and Hollis 1986). The mass accretion rate onto the hot star in R Aqr is more than $\sim 10^{-8}\ M_\odot$ yr^{-1} (Kafatos, Michalitsianos, and Hollis 1986), while less than $10^{-9}\ M_\odot$ yr^{-1} in RX Pup. Therefore, it follows that the hot component of RX Pup is more exposed, as evident in the higher excitation conditions which prevail compared with R Aqr.

IV. CONCLUSIONS

The $\sim 6''.5$ spatial extent of the bright radio/optical jet in R Aqr has enabled us to isolate C IV emission profiles in two distinct regions of emission with the *IUE* entrance aperture. The C IV $\lambda\lambda$1548, 1550 line profiles suggest a hot photoexcited gas, in which the broad line profiles, that consist of several emission components, indicate velocities that range up to more than ~ 100 km s^{-1}. The line profile structure of the C IV doublet in the compact H II region which engulfs the Mira and hot companion also indicates multiple component structure, in which the emission peaks are separated by $\Delta\bar{V} \sim 50$ km s^{-1}, similar to the C IV line profile structure which characterizes a similar system, RX Pup, where the velocity separation of emission peaks is $\Delta\bar{V} \sim 40$ km s^{-1}.

The C IV doublet intensity $I(\lambda1548)/I(\lambda1550)$ of the R Aqr H II region is ~ 0.6, i.e., is less than the optically thick limit of unity. This property of C IV emission has also been observed in other symbiotics, e.g., Z And (Cassatella, Fernandez-Castro, and Gimenez Riestra 1988), CH Cyg (Selvelli 1988) and AG Peg (Keyes and Plavec 1980). RX Pup, being intrinsically bright in far-UV emission lines compared with R Aqr, has enabled us to study this effect in greater detail. Between 1982 to 1987 the visual light declined by ~ 1.5 mag, reaching m_V(*IUE* FES) = 11.0 mag in 1987. We find an inverse relationship between the *IUE* FES *V* magnitude and C IV doublet intensity ratio $I(\lambda1548)/I(\lambda1550)$, in the sense the ratio becomes significantly less than the optically thick limit of unity as the visual light and absolute UV line intensity increases. This relationship could be explained by an optically thick wind, if the velocity range of $700 \lesssim v_{\rm wind} \lesssim 1000$ km s^{-1}. Broad P Cygni structure of the λ1550.7 line supresses emission at λ1548.2, in a manner suggested for closely spaced resonance doublets by Castor and Lamers (1979) and Olson (1982) for O and B type stellar winds. If this reasoning is applied to the C IV emission from the R Aqr H II region, it provides the only evidence for high speed motion in the system. Accordingly, the "doublet ratio-intensity effect" may provide an important diagnostic tool for studying the temporal behavior of symbiotic winds and slow novae.

We wish to thank the resident astronomers and staff of *IUE* at NASA GSFC, and particularly Y. Kondo, D. West, and R Pitts for help and assistance in completing *IUE* observations and reducing and analyzing data. This work was supported by the *IUE* Guest Investigator Program at NASA Goddard Space Flight Center.

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Note added in proof.—The $a^4F_{9/2}$–$y^4H_{11/2}$ of Fe II multiplet 45.01 is coincident in wavelength with the C IV λ1548.2 line. Pumping of Fe II by the C IV blue doublet member could decrease C IV λ1548.2 emission relative to λ1550.8, and result in Fe II fluorescence emission in the LWP wavelength range (S. Johansson, *M.N.R.A.S.*, **205**, 71P [1983]). The Fe II lines of λλ2436.20, 2458.78, 2481.00, 2492.28, 2771.15 have been observed in V1016 Cyg by H. Nussbaumer and H. Schild (*Astr. Ap.*, **101**, 118 [1981]).

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