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ABSTRACT

The C IV _1548.2,1550.8 resonance doublet in a few symbiotic stars exhibits anomalous line intensity ratios in which \( I(1548.2)/I(1550.8) \) \(< 1\), or less than the optically-thick limit of unity. Both the R Aquarii-central HII region and RX Puppis exhibit this phenomena. The \( I(1548.2)/I(1550.8) \) ratio in RX Puppis was found to vary inversely with the total C IV line intensity, and with the FES-visual light, as the object declined over a five year period following a brightening in UV and optical emission which peaked in 1982. This doublet intensity behavior could be explained by a wind which has a narrow velocity range of \( 600 < V_{wind} < 1000 \text{ km s}^{-1} \), or by the pumping of the Fe II \( \Delta \nu \, \Delta g = 2 - 3H_0 \) by C IV \( \lambda 1548.2 \), which effectively scatters C IV photons into the Fe II spectrum in these objects.

Key words: Symbiotic Stars, Stars, Atomic Spectra, Bowen Pumping, Stellar Winds

1. Introduction

Spaceborne ultraviolet spectroscopy in the near and far-UV has afforded investigators an opportunity to explore the complex emission line spectrum of symbiotic stars. These objects are believed to be a class of interacting binary, which contain a red giant or Mira variable, and a hot companion. At optical wavelengths, the presence of an ionizing radiation source in these systems is indicated by the presence of strong nebular emission, which includes [O III], [O III], [N II], [N III] [S II], He I, He II and strong Balmer series emission. In the IUE wavelength sensitivity range, the spectra of symbiotic stars are characterized by an assortment of intercombination lines, which include C III \( \lambda 1907,1909, \) [S III] \( \lambda 1882, \) N III \( \lambda 1749-1750, \) N IV \( \lambda 1487,01111 \lambda 1660,1666, \) O IV \( \lambda 1398-1401, \) as well as the permitted lines of N V \( \lambda 1238,1240, \) Si IV \( \lambda 1398, \) C IV \( \lambda 1548,1550, \) He II \( \lambda 1640 \) and Mg II \( \lambda 2795,2802. \) Often, the Bowen fluorescent lines of O III are also quite prominent. A number of symbiotics are sufficiently bright in the UV that high resolution spectra (\( \Delta \lambda \sim 0.1\lambda \) resolution) are feasible with IUE.

In at least a few of these systems \(^2,3\); there is a growing body of evidence from the line profile structure of the strong high excitation lines of C IV \( \lambda 1548,1550 \) and He II \( \lambda 1660 \) for the presence of high velocity winds of \( \sim 300 \text{ km s}^{-1} \); velocities of this magnitude are probably associated with mass expulsion from the hot companion in the system, rather than the extended atmosphere of the late type star. For example, the C IV line profile structure in RX Puppis \(^4\), AG Pegasi \(^5\) and CH Cyg \(^6\) and Z And \(^7\) exhibit broad - complex emission structure, which is probably related to mass motions in these systems, perhaps in the form of streamers or rings, formed as a result of accretion onto the hot companion.

In addition to the complex velocity structure suggested in the emission line profiles of RX Puppis, the C IV resonance doublet exhibits additional anomalous properties. Michalitsianos et al. (Ref. 8) have noted a curious effect in which the C IV doublet intensities \( I(1548.2)/I(1550.8) \) in RX Puppis and R Aquarii (central HII region) are less than the theoretical optically thick limit of one. Anomalous C IV doublet intensities, where \( I(1548.2)/I(1550.8) \) \(< 1\), have also been reported in CH Cyg \(^6\), Z And \(^7\) and AG Peg \(^5\). In the case of RX Puppis, however, the C IV intensity ratio was \( I(1548.2)/I(1550.8) \sim 0.6\), during an enhanced phase of UV and optical emission, and became larger, acquiring a value of \( I(1548.2)/I(1550.8) \sim 1\), as the star declined in UV and visual light over a five year period; i.e. the \( I(1548.2)/I(1550.8) \) was found to vary inversely with the C IV absolute intensity, and with the IUE-FES visual magnitude. This behavior we propose to call the "C IV Doublet Intensity Effect" (Ref. 8). The anomalous C IV intensities in RX Puppis have been explained in terms of a high velocity wind which has an expansion velocity in the range of \( \sim 600 \text{ km s}^{-1} \). As such, the broad P-Cygni absorption trough of the \( \lambda 1550.8 \) red doublet member absorbs emission from the \( \lambda 1548.2 \) blue doublet line \(^8\), in a manner similar to that proposed for O and B-type stellar winds. However, a high velocity wind model imposed several important conditions on both the upper and lower limiting wind velocities, as well as the optical depth properties of the expanding gas.
We wish to re-examine this interpretation and consider an alternate possibility, in which the C IV doublet intensity effect could be explained if C IV \( \lambda1548.2 \) pumps a high order multiplet (multiplet 45,01) of Fe II in a Bowen type mechanism. This process is suspected to occur in RR Tel and V1016 Cyg, based upon the presence of number of fluorescently excited Fe II lines in the UV. If such cascades of the Fe II \( ^{1}P_{1/2} \rightarrow ^{1}S_{0} \) transition of multiplet 45,01, even though the C IV doublet ratios in these objects do not appear obviously anomalous.

The merits of both models are discussed in context with our observations of RX Puppis, which have been obtained by monitoring RX Puppis in the HIRES and LORIES mode of IUE. Recently, anomalous C IV ratios, \( I(\lambda1548.2)/I(\lambda1550.8) \approx 0.6 \), have been observed in the central HII region in R Aquaril. On the other hand, the extended 65 nebulosity in this symbiotic system indicates optically-thin emission in C IV, where \( I(\lambda1548.2)/I(\lambda1550.8) \approx 2 \), appropriate to a photoexcited gas. Thus, the R Aquaril system affords an opportunity to spatially differentiate the C IV HII line-forming regions within its nebulosity in a manner not possible with other more distant, and spatially unresolved symbiotic stars, such as RX Puppis.

### 2. Discussion

A description of our five year IUE monitoring program of RX Puppis, and the first successful HIRES exposure of R Aquaril are described by Michalitsianos et al. (Ref. 8). In Figure 1, the shaded area formed by the superposition of the line profiles shows the velocity range over which the doublet ratio \( I(\lambda1548.2)/I(\lambda1550.8) \) is less than the optically-thick limit of unity. In the case of RX Puppis, the intensity ratio was \( I(\lambda1548.2)/I(\lambda1550.8) \approx 0.6 \), when the object was at maximum UV emission around March 1982. Over a five year period, RX Puppis gradually declined in UV line emission. In Figure 2, the \( I(\lambda1548.2)/I(\lambda1550.8) \) has been plotted against the total C IV doublet intensity for the observed epochs indicated. A linear relationship is evident between radio continuum knots and C IV emitting regions could be established only with high resolution sub-arcsecond imaging in the C IV lines, now only possible with HST. However, these results provide a preliminary indication establishing a correspondence between radio and UV emission from streaming material in these systems.

### 2.2 The C IV Doublet Member Intensities

#### 2.2.1 The P-Cygni Profile Interpretation

In Figure 1, the shaded area formed by the superposition of the line profiles shows the velocity range over which the doublet ratio \( I(\lambda1548.2)/I(\lambda1550.8) \) is less than the optically-thick limit of unity. In the case of RX Puppis, the intensity ratio was \( I(\lambda1548.2)/I(\lambda1550.8) \approx 0.6 \), when the object was at maximum UV emission around March 1982. Over a five year period, RX Puppis gradually declined in UV line emission. In Figure 2, the \( I(\lambda1548.2)/I(\lambda1550.8) \) has been plotted against the total C IV doublet intensity for the observing epochs indicated. A linear relationship is evident between the doublet intensity ratio and UV light. In Figure 3, a similar relationship was found between \( I(\lambda1548.2)/I(\lambda1550.8) \) and the FES-visual magnitude for this period as well.

If the "doublet ratio intensity effect" is explained by a wind, a minimum wind speed of 600 to 700 km s\(^{-1}\) is required for the doublet wavelength separation of 2.6A, in order for the absorption trough of the \( \lambda1550.8 \) line to absorb emission at \( \lambda1548.2 \). However, continuum adjacent to the absorption trough has not been detected in long duration SWP-HIRES exposures with sufficient signal to confirm the presence of broad P-Cygni structure; far-UV continuum was not detected in a 4-hour HIRES-SWP exposure in 1987. Similar duration HIRES-SWP exposures of R Aquaril-HII region also failed to detect adjacent continuum which could support this interpretation. On the
other hand, LORES-SWP (Aλ = 6Å resolution) spectra of RX Puppis and R Aquar.ii clearly indicate the presence of strong UV continuum emission in both objects.

Moreover, if such a high-speed wind is present, the curious absence of C IV P-Cygni structure in LORES-SWP spectra in both RX Puppis and R Aquar.ii places strong upper limits on $v_{\text{wind}}$, because of the limiting resolution of LORES IUE spectra. For example, $-1000$ km s$^{-1}$ P-Cygni wind profiles are detectable in LORES-SWP spectra of the planetary nebula IC 418 [14,15]. Accordingly, a narrow range of wind velocities of $600 \leq v_{\text{wind}} \leq 1000$ km s$^{-1}$ must exist, which places tight constraints on the wind velocities, such that the $v_{\text{wind}}$ is sufficiently large compared with the doublet wavelength separation, but not large enough to be detectable in LORES-SWP spectra.

![Figure 1: C IV red and blue doublet lines overplotted in velocity space. The vertical arrows indicate the radial velocity of the star. The shaded area indicates the velocity range over which the doublet intensity is less than unity. The velocities shown correspond to the velocity of individual C IV emitting regions that combine to produce the broadened profile.](image1)

![Figure 2: The C IV doublet intensities $I(\lambda1548.2)/I(\lambda1550.8)$—seven observing epochs plotted against the combined C IV emission line intensity.](image2)
Similarly, ~15-hour exposures required to detect the strongest emission lines in R Aquarii-HII region in the LWP and SMP HIRES cameras encounter similar difficulties. However, in the case of RX Puppis, IUE has sufficient sensitivity that longer exposures of ~4 hours, for a S/N ~ 10, are possible in the LWP-HIRES camera. If a direct correlation can be established between the C IV $\lambda$1548.2/\$\lambda$1550.8 intensity ratio and the strength of the fluorescent Fe II lines, the redistribution of C IV energy into the Fe II spectrum of RX Puppis would be important to establish. Because the C IV $\lambda$1548.2/\$\lambda$1550.8 ratio is related to the intrinsic UV line brightness, such a correlation could be used to determine concentration of Fe II along the absorbing pathlength during slow outbursts of the system. IUE observations are continuing to investigate this phenomena in greater detail.

3. Conclusions and Summary

The C IV $\lambda$1548.2,1550.8 emission lines in a select number of symbiotic stars exhibit complex profiles, suggestive of complex kinematic motions in the form of streamers, accretion rings and/or a disk. The C IV $\lambda$1548.2/\$\lambda$1550.8 intensity ratio also appears anomalous in a number of these systems, where the ratio is less than the theoretical optically-thick limit of unity. In RX Puppis, where this effect has been studied most extensively, the C IV $\lambda$1548.2/\$\lambda$1550.8 ratio appears to vary inversely with the total UV line emission.

We have suggested two possible explanations for this behavior which we propose to call the "C IV doublet intensity effect":

1) the broad P-Cygni absorption trough absorbs emission at $\lambda$1548.2, thus reducing the doublet ratio below the optically thick limit of unity during slow outbursts; the wind velocity in this case must be in the range $1000 \leq V_{wind} \leq 2000$ km s$^{-1}$, or

2) that owing to wavelength coincidence between Fe II and C IV, Fe II (multiplet 42.01) $^{4}P_{9}/2 - ^{4}S_{9}/2$ transition can be pumped by the blue doublet C IV at $\lambda$1548.2 line $^{10}$, effectively redistributing C IV $\lambda$1548.2 photons into the Fe II spectrum in a Bowen-type mechanism. Present IUE observations can not resolve this issue, and HIRES exposures in the LWP and SMP cameras of IUE, or with the High Resolution Spectrograph of HST, will be required to probe this effect in greater depth.

References