IUE OBSERVATIONS AND INTERPRETATION OF THE SYMBIOTIC STAR RW HYA

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ABSTRACT

IUE observations of the high excitation symbiotic star RW Hya (gM2 + pec) have been obtained. Analysis of the intense UV continuum observed between 1100 Å to 2000 Å suggests this star is a binary system in which the secondary is identified as a hot subdwarf with $T_{eff} \sim 10^5$ K. We deduce a distance to the system of $\sim$ 1000 pc. The UV spectrum consists of mainly semi-forbidden and allowed transition lines of which the CIV (1548 Å, 1550 Å) emission lines are particularly strong, and UV continuum at both shorter and longer wavelengths. Strong forbidden lines seem to be absent suggesting the presence of a nebula of high densities, in the approximate range 10^8 - 10^9 cm^{-3}. Tidal interaction between the red giant primary and the hot subdwarf is suggested as a likely means to form the observed nebula. RW Hya is suggested as a possible source of soft X-ray emission from material accreting onto the surface of the hot subdwarf. Detection of such emission with HEAO-B ("Einstein") would give us information if this accretion is taking place via Roche lobe overflow or via capture from a stellar wind emitted by the primary. A general discussion of elemental and ionic abundances in the nebula is also presented.

INTRODUCTION

RW Hydrae consists of a star of gM2 spectral type with lines in the visual characteristic of higher temperatures than would be expected for a late type giant; Merrill (ref. 1) observed H, He I, He II, [O III], [Ne III], and [Fe V], [Fe VII]. A 376 day orbital period was determined from radial velocity observations of emission and absorption lines by Merrill (ref. 1).

Our IUE results confirm the binary hypothesis of Merrill. The star system consists of the late type giant and a hot companion which we classify as a central star of a planetary nebula. The two stars are immersed in a dense nebula which gives off intense allowed and semi-forbidden lines, the strongest ones being the C IV doublet. IUE is particularly useful in observing late type stars that have composite spectra, since the luminosity of the primary M giant does not overwhelm the emission from the companion in the far UV.

UV OBSERVATIONS

Ultraviolet observations were obtained of RW Hya on July 29 and September 1 1979 over the wavelength range 1100 A to 3200 A using exclusively the 10" x 20" large aperture of the IUE spectrometer. Virtually no change was seen in the spectrum observed during the two observing sessions. In Figure 1a,b we show the short and long wavelength observations of RW Hya. Ly α 1216 Å is observed in absorption. The C IV lines are so strong that subsequent exposures of 30 seconds obtained on September 1 saturated one pixel! High dispersion ($\sim$ 0.1 Å resolution) spectra obtained on September 1 in the short wavelength region revealed a number of allowed and semi-forbidden lines. We have identified 39 lines in the spectrum of RW Hya and have possible candidates for 12 others. In Table I we show line identifications and fluxes for the strongest IUE features. Other numerous lines of the ions in Table I were also observed (e.g the CIII 1174.9 - 1175.8 Å lines, the O I] 1355.6 Å line etc.). Moreover, we identified lines of the (43) and (68) multiplets of Fe II, the Si II 1808 + 1817 Å lines and the Al III 1854.7, 1862.8 Å lines.Twelve possible lines that we observed are a number of Fe II features, a Si III feature and some forbidden [Ne III] ,[Ne IV],[O II],[O III]lines. These are very tentative identifications and we are very skeptical whether in fact any forbidden line was seen. In contrast to the short wavelength region which is rich in lines we only detected definite lines CII], Mg II and O III in the long wavelength region (see Figure 1 and Table I). The short wavelength continuum drops as the Rayleigh-Jeans black body tail of a hot star emission would be expected. Beyond about 2000 Å,F_λ is essentially constant with wavelength.

DATA ANALYSIS

From equivalent width measurements of the Ly α absorption line we obtain a column density of H I in our line of sight $N_{H\,I} \sim 6.4 \times 10^{18}$ cm^{-2}. Using the interstellar extinction relationship (ref. 2), we find E(B-V) $\sim 1.3 \times 10^{-3}$. This low value of extinction is consistent with the 1200 Å to 1700 Å Rayleigh-Jeans excellent fit to the observed continuum. We estimate a lower limit to the temperature of the hot component $T_2 \sim 50{,}000$ K (if, for example, the star had a temperature of 30,000 K, the black body maximum would be in the 1000 Å region of the spectrum and would not follow the observed Rayleigh-Jeans tail).

We estimate the absolute magnitude of the primary as $M_V \sim 0.0$, although it could be slightly smaller. From the observed apparent magnitude of $m_V \sim 10$, we obtain a distance of $\sim$1000 pc and a height above the galactic plane of $\sim$ 600 pc. The corresponding stellar parameters are $M_{bol} \sim -2.2$, log $L_*/L_\odot \sim 2.8$ and log $R_*/R_\odot \sim 1.9$.

The apparent magnitude of the secondary was obtained from the observed Rayleigh-Jeans tail, $m_V \sim 14.75$, and therefore the secondary is much fainter than the primary in the visible. We estimate an upper limit to its temperature $T_2 \sim 200{,}000$ K in order not to violate the Eddington limit for a star of 1 $M_\odot$. The stellar parameters for an intermediate temperature T_2 = 100,000 K are $M_{bol} \sim -3.0$, log $L_*/L_\odot \sim 3.1$ and log $R_*/R_\odot \sim -0.9$. Such a star is in the middle of the central star of planetary nebula region (ref. 3).

Between 2000 Å and 3200 Å the continuum contribution by the companion is assumed negligible in comparison to the nebular continuum. We attribute the continuum in this range to Balmer recombination for reasons that will be made evident further in the text. At 2400 Å the measured continuum flux is $F_\lambda \sim 5\times10^{-13}$ ergs cm^{-2} s^{-1} A^{-1} and yields a relation for continuum emission for an ionized nebula which is (ref. 3)

$$n_e^{\,2}\ (L/L_o)^3\ D_{1000}^{-2} \sim\ 3.45 \times 10^{18} cm^{-6} \qquad (1)$$

where n_e is the electron density in the nebula and L the linear size of the nebula scaled to $L_o \equiv a_o$, a_o is the semi-major axis of the elliptical orbit for a mass ratio of the two stars $M_1/M_2 \sim 2$, $M_2 \sim 1\ M_\odot$ and an assumed orbital period $\sim$ 376 days (ref. 1).On the other hand, from the Stromgren sphere relation we have

$$n_e^{\,2}\ (L/L_o)^3 \sim 1.26 \times 10^{19}\ N_{47}\ cm^{-6} \qquad (2)$$

where N_{47} is the number of ionizing photons emitted per sec in units of 10^{47} s^{-1}. Accordingly, taking the distance to the system as $D_{1000} = 1$, we require $N_{47} \sim 0.3$ and therefore $T_2 \lesssim$ 100,000 K.

The strength of all the observed lines is proportional to $n_e^{\,2}\ L^3$ since collisional de-excitation would have to be negligible because of the existence of the semi-forbidden lines. The estimated upper limit to the electron density would then be $\sim 10^9\ cm^{-3}$. Using the atomic data (ref. 3,4,5,6) we computed the theoretical line strengths. Taking all the ions present, one may estimate the elemental abundances for different nebular temperatures, T_e. We find the most reasonable abundances for $T_e \sim$12,500 K, otherwise some elements are too overabundant or too underabundant with respect to the solar values. Using a number of arguments involving the absence of forbidden lines in the UV, the presence of the forbidden lines observed in the visible (ref. 1), the C III / C III] ratio, the ratios of lines in the O IV] multiplet and the absence of the two photon continuum, we estimate the approximate range of the densities in the nebula to be 10^8 - 10^9 cm^{-3} and the corresponding range of linear sizes 3×10^{14} - 6.5×10^{13} cm. We obtain reasonable ionic abundances from the observed line fluxes, with one exception, He III being underabundant by a factor of 10. It may very well be that the temperature of the secondary is in the low part of the range we estimated, $T_2 \lesssim$ 50,000 K. The observed flat continuum above 2000 Å would then have to be due to something other than photoionization by the hot companion.

The low excitation lines of O I, Si II, Mg II and Fe II may be originating from different regions than the compact, ionized nebula. A cool chromosphere is possible, although the various possibilities cannot be distinguished.

TIDAL INTERACTION

It is interesting to note that for $n_e \sim 10^9 cm^{-3}$, the size of the nebula would only be about five times the primary radius. Using an escape velocity from the primary of 100 km s^{-1} we estimate the steady state mass loss from the primary required to be 6×10^{-6} $M_{\odot}$ yr^{-1} for $n_e \sim 10^8$ cm^{-3} and 3×10^{-6} $M_{\odot}$ yr^{-1} for $n_e \sim 10^9$ cm^{-3}. These rates seem to be high for the primary in the general region of the H - R Diagram (ref. 7), which we would have expected to be less than $\sim 3 \times 10^{-7}$ $M_{\odot}$ yr^{-1}. It is interesting to note that the symbiotic star GX 1+4 seen to emit X-rays (ref. 8) has a nebula with radius and density similar to that of RW Hya. Its luminosity, however, at X-rays is high, $\sim 4 \times 10^{37}$ ergs s^{-1}. HEAO-2 ("Einstein") observations of RW Hya would be very useful. If Roche lobe overflow-a likely possibility-is occurring, we expect an X-ray luminosity of RW Hya comparable to GX 1+4; if capture from a stellar wind is occurring, more modest X-ray luminosities would be observed ($\sim 10^{34}$ ergs s^{-1}).

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TABLE 1.- LINE IDENTIFICATION AND FLUXES

Ionic Transition	Wavelength (A)	Wavelength of IUE Feature (A)	Flux (ergs cm^{-2} s^{-1})
S V]	1199.180	1199.200	1.56×10^{-12}
N V	1238.82+1242.8	1238.836+1242.82	2.73×10^{-11}
O I	1302.169 etc.	1302.468 etc.	1.83×10^{-11}
Si IV	1393.755	1393.930	
O IV]	1399.774	1399.810	
O IV]	1401.156	1401.198	5.08×10^{-11}
Si IV	1402.770	1402.928	
S IV] + O IV]	1404.770+1404.81	1404.770	
S IV]	1406.000	1406.084	
O IV]	1407.386	1407.414	
N IV]	1486.496	1486.512	5.59×10^{-11}
C IV	1548.185+1550.77	1548.448+1550.97	3.89×10^{-10}
He II	1640.332	1640.412	2.07×10^{-11}
O III]	1660.803	1160.914	4.10×10^{-11}
O III]	1666.153	1666.248	
N III]	1748.610	1748.840	
N III]	1749.674	1749.794	8.27×10^{-12}
N III]	1752.160	1752.378	
N III]	1753.986	1754.164	
Si III]	1892.030	1892.172	4.27×10^{-12}
C III]	1908.734	1908.922	5.76×10^{-11}
C II]	2325+2327+2328	2332.4	2.43×10^{-11}
Mg II	2796+2803	2799.4	1.00×10^{-11}
O III	3047	3040.0	9.70×10^{-12}
O III	3193	3141.6	2.62×10^{-11}

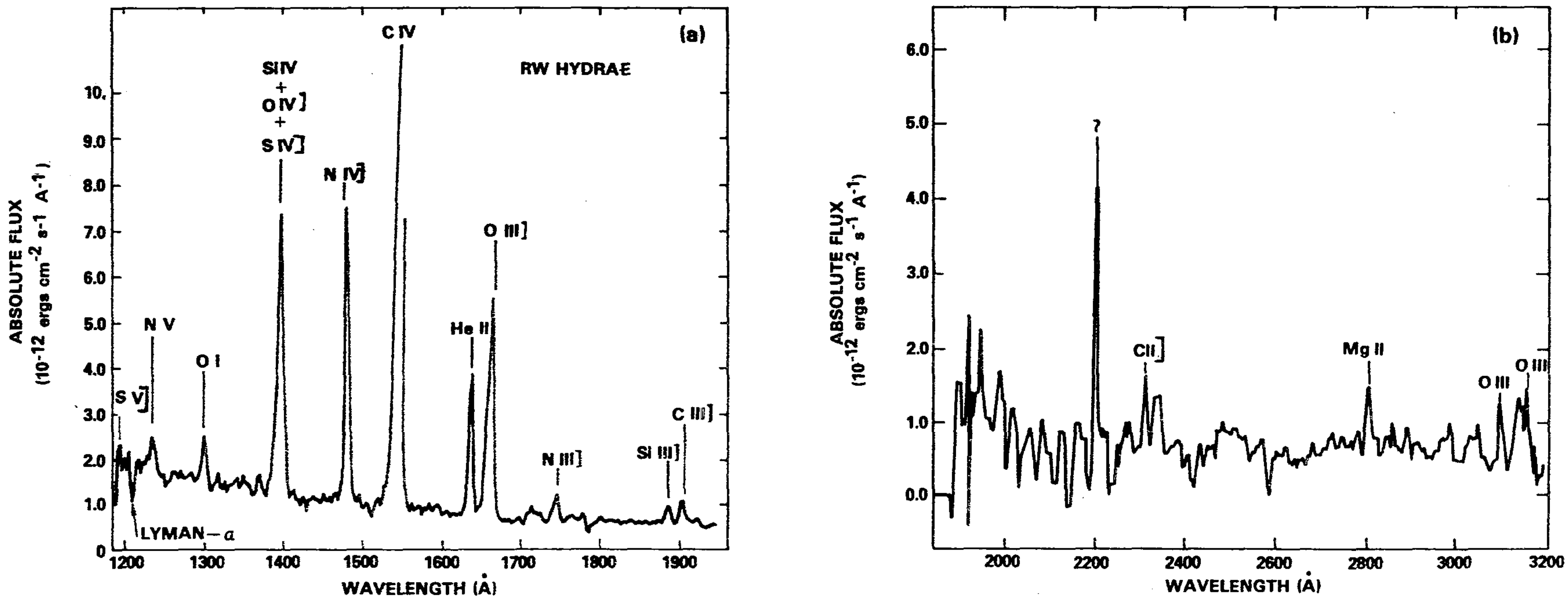
(a)
RW HYDRAE
C IV
Si IV + O IV] + S IV]
N IV]
O III]
He II
N V
O I
S V]
LYMAN−α
N III]
Si III]
C III]
ABSOLUTE FLUX
(10⁻¹² ergs cm⁻² s⁻¹ Å⁻¹)
WAVELENGTH (Å)
(b)
?
C II]
Mg II
O III
O III
ABSOLUTE FLUX
(10⁻¹² ergs cm⁻² s⁻¹ Å⁻¹)
WAVELENGTH (Å)

FIG. 1.