UV LINE EMISSION OF SYMBIOTIC STARS

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ABSTRACT

General characteristics of emission line spectra from symbiotic stars are outlined. Data from some special line ratios in the 1000 Å - 3000 Å range, and others connecting the visual and the far UV lines are presented, and their application to symbiotic stars is discussed. Integrated fractional abundances for ions easily observed in the far UV are given to facilitate abundance determinations for nebular conditions. It is found that the physical conditions of the regions emitting the emission line spectra differ considerably among different symbiotic stars.

1. INTRODUCTIONARY REMARKS

In this review I concentrate on the diagnostic possibilities offered by studying the IUE (International Ultraviolet Explorer) line spectra, the continuum will be treated by Slovak (1982). The nebular spectrum as seen in the visual already tells us, that symbiotic objects contain emission regions where elements are typically one to three times ionised, with some higher ionisation stages for heavier elements. The well known [N II], [O III], [Fe VII] and other nebular lines appear with intensity ratios showing that electron temperatures and densities of $T_e > 10^4$ K and $N_e > 10^5$ cm^{-3} prevail. At 1100 Å < λ < 3200 Å we not only expect to observe the strong resonance and intercombination lines from the ions already observed in the visual, but also those ions which do not possess low lying metastable levels, such as the very important missing links like C^{2+}, C^{3+}, N^{2+}, N^{3+}, O^{3+}.

M. Friedjung and R. Viotti (eds.), The Nature of Symbiotic Stars, 85–102.

2. THE UV SPECTRA (1100 Å - 3300 Å)

2.1. General appearance

The UV spectra of symbiotic stars are characterised by emission lines from neutral to several times ionised atoms. The easily observed emission lines are much stronger than the underlying continuum; absorption features can occasionally be detected. In some symbiotic objects high ionisation spectra such as N V, Ne V, Mg V (and perhaps Fe VII) are observed, whereas in others only once or twice ionised atoms are detected. As examples I show in Figure 1 the spectra of Z And (Altamore et al. 1981) and RW Hya (Kafatos et al. 1980). From these figures and other descriptions (e.g. Penston et al. 1981, Nussbaumer and Schild 1981) we find the typical nebular lines: recombination lines of He I, He II, the collisionally excited allowed, forbidden, and semiforbidden lines originating from the energetically lowest terms, as well as the O III Bowen lines excited by resonant absorption of He II Ly α. The identified Fe II multiplets form a contrast by not being restricted to resonance multiplets like UV 1, 2, 3, they cover the whole Fe II bound state energy domain. CH Cyg shows a different picture; its spectrum alternates between one with absorption lines of high ionisation stages (C III, C IV, N V etc.) and emission lines of singly ionised and neutral atoms (Hack 1979).

2.2. Preliminary conclusions about electron temperatures and densities

At a first glance these spectra could be mistaken for those of planetary nebulae. However, inspection of the C III λλ1907, 1909 doublet high resolution spectra (or descriptions) published by Keyes and Plavec (1980) (AG Peg), Kafatos et al. (1980) (RW Hya), Penston et al. (1981) (RR Tel), Nussbaumer and Schild (1981) (V 1016 Cyg), Altamore et al. (1981) (Z And), shows that in all these objects the λ1909 component is much stronger than the usually absent λ1907 line. According to Figure 5 of Nussbaumer and Schild (1979) we can therefore safely assume that the region emitting C III has electron densities $N_e > 10^6$ cm^{-3}. Altamore et al. (1981) have studied the N III] multiplet at λ1749 emitted by Z And. With the relative emissivities calculated by Nussbaumer and Storey (1979) they find $N_e \approx 2 \cdot 10^{10}$ cm^{-3}. They find the same result when studying the O IV] λ1401 multiplet for which the relative emissivities were calculated by Flower and Nussbaumer (1975). Penston et al. (1981) find for RR Tel $N_e \approx 5 \cdot 10^6$ cm^{-3}, this from the already mentioned C III λ1908 and from N IV] λ1485 for which the relative emissivities are given in Figure 2 of Nussbaumer and Schild (1981). For V 1016 Cyg Nussbaumer and Schild (1981) find $N_e \approx 3 \cdot 10^6$ cm^{-3} mainly from the N IV] λ1485 multiplet.

From symbiotic UV spectra thus far investigated we obtain $10^6 < N_e[\mathrm{cm}^{-3}] < 10^{11}$. This is considerably higher than the typical value of $N_e \lesssim 10^4$ cm^{-3} found in planetary nebulae, though for the young

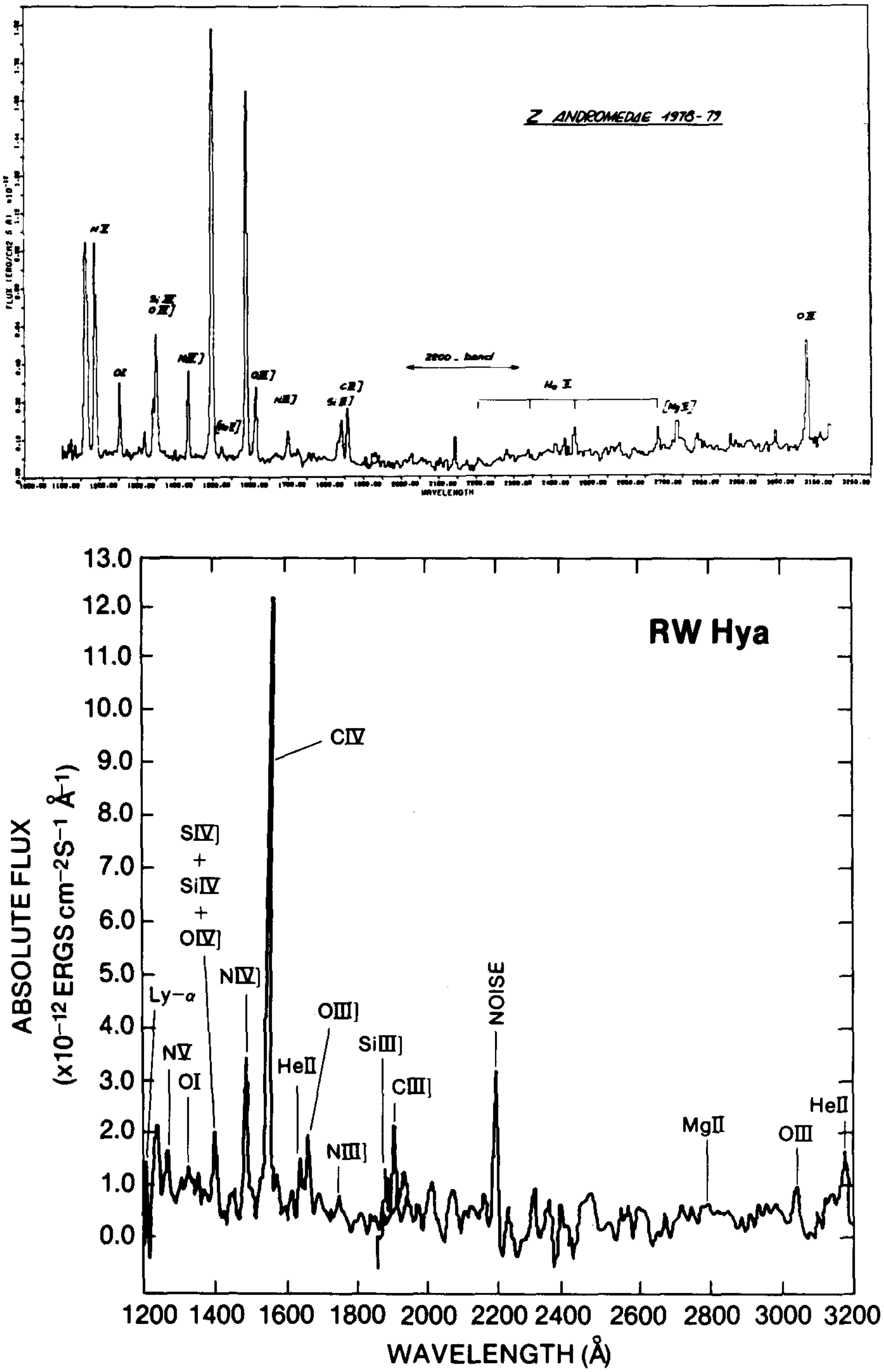

Figure 1. IUE low resolution spectra

planetary nebula IC 4997 a density of $5 \cdot 10^5$ cm^{-3} was derived by Flower et al. (1979); as a reminder: the innermost part of the solar corona has 10^8 cm^{-3} $\lesssim N_e \lesssim 10^9$ cm^{-3}.

What about the electron temperatures at which these spectra are emitted. For Z And Altamore et al. (1981) derive 60000 K $\lesssim T_e \lesssim$ 80000 K. To find this result they have assumed C III] and N III] to be emitted from the same geometrical region; as a first approximation this is probably justified. They are on shakier grounds with the additional assumption that the abundance ratio N/C has the solar value (see next section). For V 1016 Cyg Nussbaumer and Schild (1981) find 8000 K $< T_e <$ 25000 K; this temperature results from energy balance calculations and is thus very model dependent. For RR Tel Penston et al. (1981) claim excitation temperatures of 12000 K to 19000 K. This claim is backed by comparing recombination lines with resonance lines, like C III λ2296 with C IV λ1550 (for the theory see Storey (1981)). However, the temperatures thus found are only limits. They also call on the Si II lines λλ1264, 1533, 1817; from their relative intensities they deduce $T_e \approx$ 12000 K. But Jordan (1969) who calculated the relevant emissivity ratios found large discrepancies between observation and calculation which she blamed on the quality of the atomic data; from my own experience with Si II (Nussbaumer 1977) I cannot but share her suspicion. From the O III λλ2321, 1660, 1666 they find T_e = 19000 K by assuming $N_e \approx 10^5$ cm^{-3}, but with their previously determined $N_e \approx 5 \cdot 10^6$ cm^{-3} the curves of Nussbaumer and Storey (1981) give $T_e \approx$ 40000 K for the observed ratios in RR Tel.

For RW Hya Kafatos et al. (1980) opt for T_e = 12500 K. They chose this temperature because they find that abundances of C, N, O, Si, S determined with a model of this temperature fit the cosmic abundances best; although they do not force a cosmic abundance on their model, indeed they find some significant abundance differences.

Sahade (1980) considers that the simultaneous presence of Mg II, N V and intermediate ionisation stages indicates a large range in excitation temperatures. Sahade may be right that some symbiotic spectra originate in chromospheres, coronae, or their transition regions, but a N V itself is no proof of $T_e \approx 10^5$ K; in the V 1016 Cyg model of Nussbaumer and Schild (1981) the N V doublet is formed at $T_e \approx$ 25000 K.

2.3. Abundances

For symbiotic stars the IUE wavelength range provides very advantageous conditions for determining relative abundances, in particular of C, N, O and He. For C, N, O the collisionally excited ground state transitions of the different ionisation stages are available. From He we observe recombination lines like He II λ1640 and the n → 3 series (λλ3203, 2733, 2511, 2385 etc.) and He I recombination lines like some of the 2s ^3S - np ^3P lines. To determine abundances relative to H, we have to rely on lines of the Balmer series.

Nussbaumer (1980) has tabulated relative abundances of planetary nebulae as determined with IUE observations. For O/H where the solar value is $8.3 \cdot 10^{-4}$ the planetary nebula ratios vary from $1.1 \cdot 10^{-4}$ to approximately solar; for C/N where the solar ratio is 4.7, planetary nebula ratios vary from 0.5 to 6. This should warn us against assuming that symbiotic stars have solar abundances, when planetary nebula show such large variations. A review on abundance determinations and related problems, with a large number of references for gaseous nebulae has been given by Peimbert (1980). The C, N, O, He abundance is of central interest when trying to form an evolutionary picture of our objects; so are Si and Mg when investigating dust formation. Of these elements the most elusive is Mg. It is very likely to be present mainly as Mg^{2+}, but there are no Mg III lines in either the visual or the IUE wavelength range. The situation is as bad with Mg IV and only Mg V $2p^4\ ^3P - {}^1D$ λλ2783, 2929 establish contact with Mg. Mg II λλ2796, 2803 are of course well known and observed. However, as Mg^+ can also exist in the H^0 region of our objects, self absorption in that doublet may be substantial; interstellar absorption proper, due to its small line width, could be more easily disentangled.

An abundance determination based on the λ < 3000 Å spectra is that of Nussbaumer and Schild (1981) for V 1016 Cyg. I list their results (model 2) to compare them with solar abundances (logarithmic abundances relative to 12 for hydrogen); the solar ratios are from Lambert (1978) for C, N, O, and from Withbroe (1971) for the other elements.

	He	C	N	O	Ne	Mg	Si
V 1016 Cyg	11.30	8.28	8.08	8.43	8.00	7.85	7.11
Sun		8.67	8.00	8.92	7.50	7.54	7.55

We have thus at least one symbiotic object with abundance ratios different from the sun, and it would be astonishing if it remained the only one.

Can we determine relative abundances in a simple way? The total energy from the m times ionised atom X in the transition i → j is

$$L_{ij}\ (X^m) = \int_V N(X_i^m)\ A_{ij}\ h\nu_{ij}\ dV \qquad (1)$$

$N(X_i^m)$ is the particle density of the m times ionised element X in the state i. In the case we treat, the integral will cover the H^+ region. We shall assume constant T_e and N_e throughout the emitting region. With the expansion

$$N(X_i^m) = \frac{N(X_i^m)}{N(X^m)} \cdot \frac{N(X^m)}{N(X)} \cdot N(X) \qquad (2)$$

and defining

$$P(X^m) = \int_V \frac{N(X^m)}{N(X)}\, dV \,, \qquad (3)$$

the expression for L_{ij} takes the form

$$L_{ij}(X^m) = \frac{N(X_i^m)}{N(X^m)} \cdot N(X) \cdot P(X^m) \cdot A_{ij}\, h\nu_{ij} \qquad (4)$$

where

$$N(X) = \sum_n N(X^n), \text{ and } N(X^n) = \sum_i N(X_i^n) \,. \qquad (5)$$

As we are mainly interested in lines which are excited from the ground term, we shall work with the most simple atomic model: (a) the atom consists of 2 states, (b) the lines are optically thin, (c) the upper state is collisionally excited from the ground state and radiatively de-excited (no collisional deexcitation); (b) may be problematic for allowed lines and (c) for intercombination and forbidden lines. In an equilibrium situation the relation

$$N(X_1^m)\, q_{1i}\, N_e = N(X_i^m) A_{i1} \qquad (6)$$

is valid. The collisional excitation rate coefficient is defined as

$$q_{mn} = \frac{8.63 \cdot 10^{-6}\; T_{mn}}{g_m \;\sqrt{T_e}} \exp\,(-\Delta E_{mn}/k\, T_e) \qquad [\mathrm{cm}^3 \mathrm{s}^{-1}] \qquad (7)$$

g_m is the statistical weight of the state m, and T_{mn} is the averaged collision strength. The emitted luminosity ratio of two lines of the elements X and Y is

$$\frac{L_{ij}(X^m)}{L_{k\ell}(Y^n)} = \frac{N(X)}{N(Y)}\; \frac{N(X_i^m)}{N(X^m)}\; \frac{N(Y^n)}{N(Y_k^n)} \circ \frac{P(X^m)}{P(Y^n)}\; \frac{A_{ij}}{\lambda_{ij}} \circ \frac{\lambda_{k\ell}}{A_{k\ell}}$$

$$= \frac{N(X)}{N(Y)}\; \frac{P(X^m)}{P(Y^n)}\; \frac{T_{ij}\; g_\ell\; \lambda_{k\ell}}{T_{k\ell}\; g_j\; \lambda_{ij}} \circ e^{-(E_i - E_k)/k\, T_e} \qquad (8)$$

The observed flux ratio is

$$\frac{F^{obs}_{ij}(X^m)}{F^{obs}_{k\ell}(Y^n)} = \frac{L_{ij}(X^m)}{L_{k\ell}(Y^n)} \cdot 10^{-c(f(\lambda_{ij})-f(\lambda_{k\ell}))} \qquad (9)$$

where the extinction curve $f(\lambda)$ could for example be obtained from Seaton (1979) and the extinction coefficient c has to be determined separately. Disregarding the error sources in our primary assumption as well as those in F^{obs}, c, f, T, the remaining unknown quantities are the ratio $P(X^m)/(P(Y^n)$ and the temperature T_e. Accepting the dangerous assumption of constant T_e, we may ask how strongly the uncertainty in the absolute value of T_e effects the resulting N(X)/N(Y). Take as an example a N(C)/N(O) determination with the lines O III λ1666 and C III λ1909. The upper states of the two transitions differ by 7614 cm^{-1} : = 1.49 10^{-12} erg. The function $\exp(-(E_i-E_k)/kT)$ thus has values of 0.34, 0.49, 0.58, 0.76, 0.90 for $T_e/10^4$ K = 1, 1.5, 2, 4, 10. With a reasonable notion of T_e the error in N(C)/N(O) should be $\lesssim$ 30%.

I have calculated $P(X^m)$ for several elements for the following conditions. A central star with a blackbody radiation of temperature T* and radius R* ionises a spherically symmetrical nebula with constant N_e and T_e, which begins at a radial distance r, and is semi-infinite. $P(X^m)$ is calculated for the region where H is ionised; in that region most of the elements of Table 1 will be at least singly ionised. When obtaining the results of Table 1 the dielectronic recombination coefficients of Aldrovandi and Péquignot (1973) were employed. But for $T_e \lesssim 20000$ K autoionising states lying just above the first ionisation edge can significantly influence these dielectronic recombinations, as has been shown by Storey (1981). Thus, shifts in the ionisation balance have to be expected as more accurate recombination coefficients become available.

From Table 1 we see that for the conditions mentioned, the twice and three times ionised elements constitute mostly more than half of the total abundance. Thus extending expressions (8) to the two most important of the observable ionisation stages should already permit good estimates. Table 1 cannot replace a proper model calculation, but a feeling for the effects of variations in some of the relevant physical parameters can be acquired; it can serve to estimate relative abundances and to correct for unobserved ionisation stages.

Table 1 Integrated relative fractional abundances $P(X^m)/\sum_i P(X^i)$ for singly (m=1) and more highly ionised atoms

		T_e = 15000 K N_e = 10^6 cm^{-3}					T_e = 40000 K N_e = 10^6 cm^{-3}				
	T*	m=1	2	3	4	5	m=1	2	3	4	5
He	60000	0.96	0.02				0.93				
	100000	0.95	0.04				0.96	0.04			
	150000	0.83	0.17				0.84	0.16			
	200000	0.69	0.31				0.71	0.29			
C	60000	0.13	0.86	0.07			0.47	0.49			
	100000	0.01	0.66	0.32			0.11	0.79	0.09		
	150000		0.32	0.56	0.12		0.06	0.58	0.24	0.11	
	200000		0.22	0.52	0.26		0.05	0.44	0.27	0.24	
N	60000	0.44	0.54	0.07			0.51	0.47			
	100000	0.07	0.52	0.40			0.11	0.66	0.23		
	150000	0.04	0.24	0.59	0.09	0.04	0.06	0.40	0.48	0.03	0.03
	200000	0.03	0.16	0.51	0.08	0.22	0.04	0.29	0.45	0.03	0.19
O	60000	0.50	0.49				0.52	0.47			
	100000	0.07	0.89	0.03			0.09	0.88	0.03		
	150000	0.03	0.78	0.05	0.11	0.02	0.05	0.80	0.06	0.09	
	200000	0.02	0.65	0.03	0.10	0.16	0.04	0.68	0.04	0.16	0.06
Ne	60000	0.53	0.47				0.41	0.58			
	100000	0.05	0.91	0.04			0.05	0.92	0.03		
	150000	0.02	0.79	0.05	0.11	0.02	0.02	0.81	0.04	0.10	0.02
	200000	0.01	0.65	0.27	0.11	0.18	0.02	0.68	0.02	0.10	0.16
Mg	60000	0.08	0.48	neutral Mg: 0.44			0.04	0.54	neutral Mg: 0.43		
	100000	0.04	0.85	0.03			0.02	0.85	0.03		
	150000	0.02	0.74	0.07	0.11	0.01	0.01	0.76	0.05	0.11	0.02
	200000	0.02	0.60	0.03	0.12	0.20	0.01	0.62	0.02	0.09	0.21
Si	60000	0.20	0.76	0.04			0.51	0.42			
	100000	0.08	0.43	0.35	0.13		0.41	0.47	0.05	0.04	
	150000	0.05	0.16	0.28	0.50		0.26	0.32	0.08	0.31	0.01
	200000	0.04	0.10	0.20	0.50	0.16	0.19	0.23	0.06	0.32	0.18

3. CIRCUMSTELLAR OR NEBULAR EMISSION

Altamore et al. (1981) consider that in Z And the emission lines are formed in a solar type transition region around the M 6.5 star. In such a transition region the ionisation of the elements is mainly due to collisions by free electrons, and the ionisation temperature T_{ion} is approximately equal to the electron temperature T_e; where T_{ion} is defined as the electron temperature T_e, at which a given ion reaches its maximum fractional abundances when subjected to collisional ionisation. For V 1016 Cyg Nussbaumer and Schild (1981) propose a planetary nebula type model. In that case ionisation is due to the radiation field of the central star and for stellar temperatures we are probably concerned with,

($T^* < 200000$ K) one finds $T_e < T_{ion}$. C IV may serve as a practical example. According to Nussbaumer and Storey (1975) C^{3+} has $T_{ion} \approx 90000$ K but in the V 1016 Cyg model C IV is mainly emitted at $T_e \approx 15000$ K. (Examples of curves of fractional ionisation for several elements may be found in Jordan (1969)). Michalitsianos et al. (1980) consider the UV line emission from R Aqu to originate from a $N_e \approx 10^6$–10^7 cm^{-3}, $T_e \approx 15000$ K nebula of a few times 10^{14} cm, placed around a M7 star and ionised by a white dwarf placed at the edge of the nebula. Hack (1979) after including the IUE spectra in her study of CH Cyg is still undecided on the model to opt for. Analysing the low resolution spectra of the four symbiotic stars YY Her, SY Mus, CL Sco, BX Mon Michalitsianos et al. (1981) tend towards a double star model with an accretion disc. Are all these models realised to some degree, or are some of the models just fantasy? Progress could be more easily achieved if we had better notions about T_e, in particular if we could decide whether $T_e \approx T_{ion}$ or $T_e \neq T_{ion}$. For the well observable lines in the IUE domain there are not many pairs of lines fulfilling the requirements for T_e determination. The O III lines at λλ2322, 1667 are fine for $N_e \lesssim 10^4$ cm^{-3}, for higher N_e that ratio is strongly density dependent, and up to now all the UV emitting regions of symbiotic stars have been found with $N_e > 10^5$ cm^{-3}. The case is similar for [Ne IV] for which Penston et al. (1981) give the following vacuum wavelengths: $\lambda(^4S^o_{3/2} - {}^2D^o_{3/2}) = 2424.97$, $\lambda(^4S^o_{3/2} - {}^2D^o_{3/2}) = 2422.43$, $\lambda(^4S^o_{3/2} - {}^2P^o) = 1601.5$. I have calculated the intensity ratio for a range of N_e and T_e embracing those found in symbiotic stars, with collision strengths and transition probabilities from Giles (1980) and Zeippen (1981). The emissivity ratios $\varepsilon(\lambda 1601)\varepsilon/(\lambda 2424)$ of the total multiplets $^4S^o - {}^2P^o$ and $^4S^o - {}^2D^o$ are given in Fig. 2. The ratio is a good T_e indicator for $N_e < 10^4$ cm^{-3} and for $N_e > 10^8$ cm^{-3}. Thus for Z And where Altamore et al. (1981) derive $N_e \cong 2 \cdot 10^{10}$ cm^{-3} the [Ne IV] ratio is insensitive to density variations and should allow an accurate T_e determination; the practical problems will be the simultaneous detection of both multiplets. Penston et al. (1981) observe in RR Tel $F(\lambda 1601)/(F(\lambda 2422) + F(\lambda 2424)) = 2.6$. As the reddening in the two multiplets is comparable we neglect this effect for the present qualitative discussion. This ratio is compatible with $10^6 < N_e$ [cm^{-3}] $< 10^7$ for any T_e.

In the visual spectra of some symbiotic stars [Fe VII] is detected. Some work on the visual lines of [Fe VII] was done by Nussbaumer and Osterbrock (1970), however they omitted the transitions from $3d^2\ ^1S$. From Ekberg (1981) we now know the energy of this term, the strongest transition from ^1S occurs at 2015 Å. Penston et al. (1981) list for RR Tel an unidentified feature at λ2015.33. This transition when compared to the other forbidden [Fe VII] lines, is exceedingly sensitive to variations in T_e in the range $T_e \lesssim 60000$ K, as is shown in Fig. 3 (Fig. 3 is based on a preliminary I configuration calculation of Nussbaumer and Storey (1982)). But we need calibrated fluxes in the visual domain.

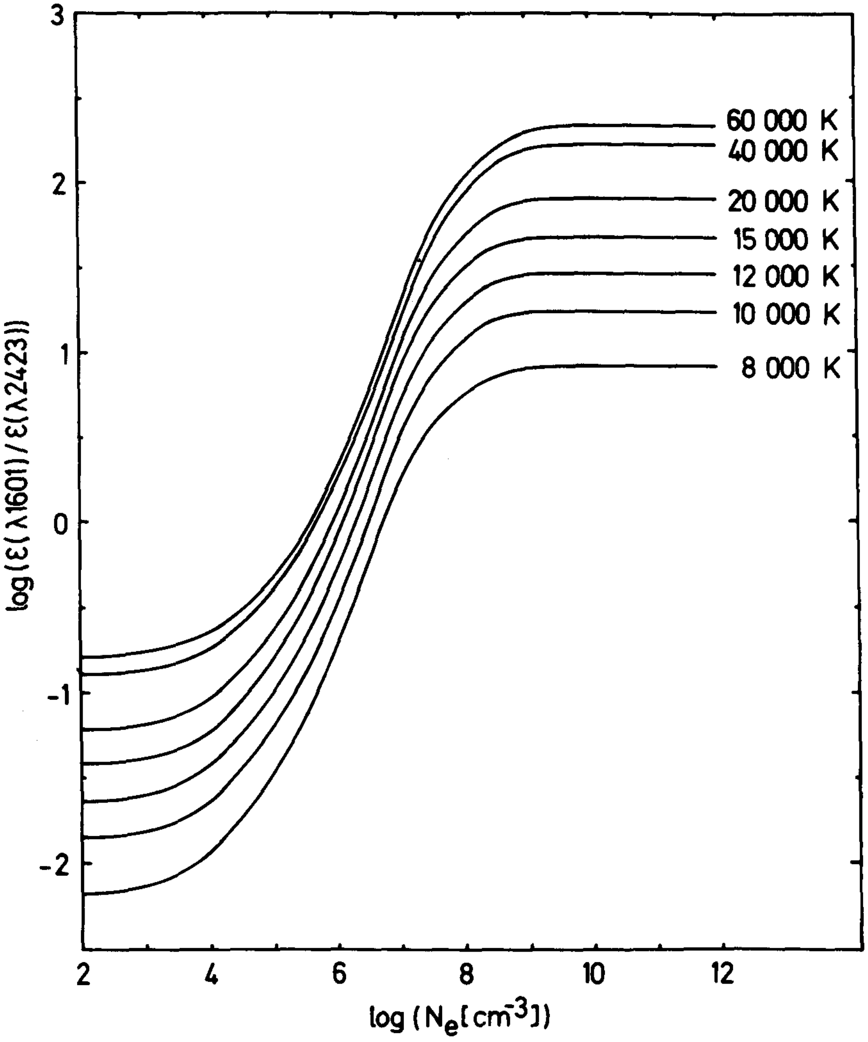

Figure 2. [Ne IV]: Ratios of emissivities in the multiplets $\varepsilon(^4S^o - {}^2P^o)/\varepsilon(^4S^o - {}^2D^o) = \varepsilon(\lambda1601)/\varepsilon(\lambda2423)$. The doublet at λ2423 consists of λλ2422, 2423; the λ1601 components should be separated by approximately 0.2 Å. ε was calculated in erg/s per ion.

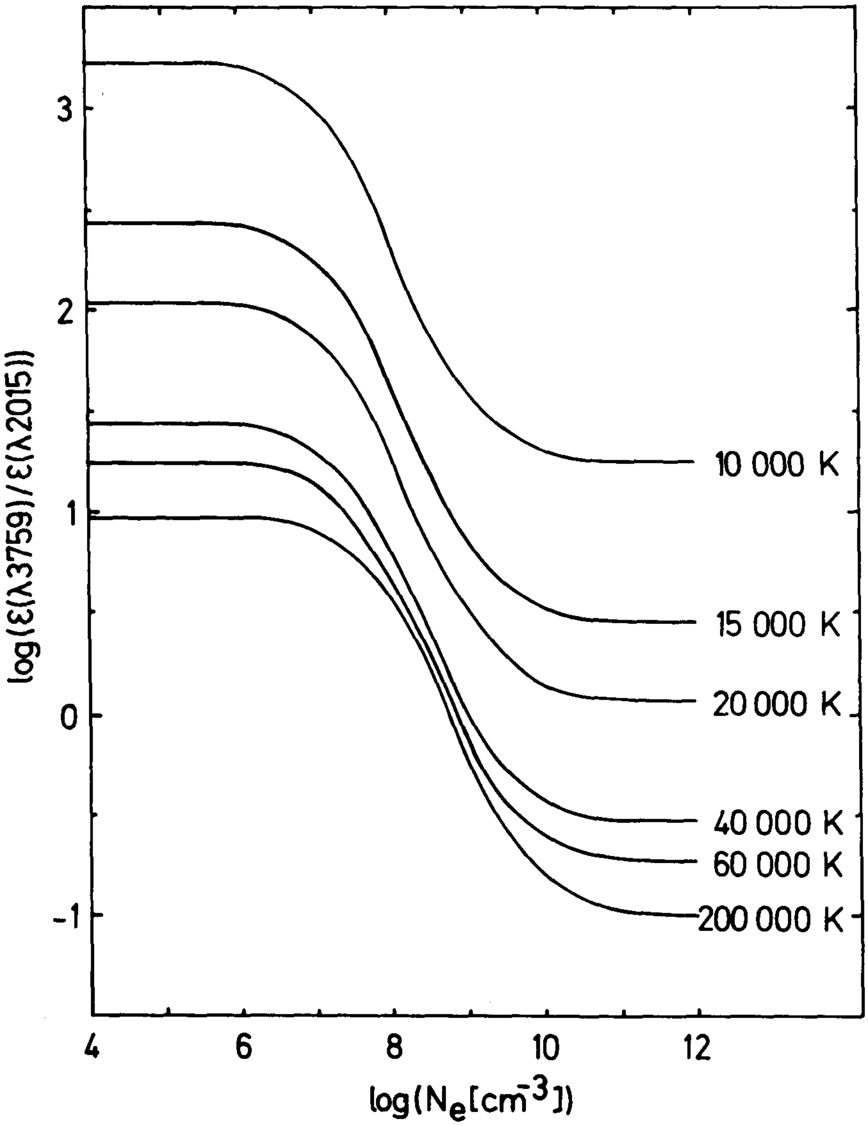

Figure 3. [Fe VII]: Ratios of emissivities in the lines $(^3F_4 - {}^1G_4)/\varepsilon(^1D_2 - {}^1S_0) = \varepsilon(\lambda3759)/\varepsilon(\lambda2015)$

In Z And [Fe VII] λ3758 is one of the most prominent emission lines (Figure 4 of Altamore et al. 1981). If Altamore et al. are right with their estimate of $N_e \approx 2\cdot10^{10}$ cm^{-3}, $T_e \approx 4\cdot10^{4}$ K, then the unreddened flux in λ2015 should be approximately three times as strong as in λ3758; with $E_{B-V} \approx 0.3$ this ratio will be reduced by approximately a factor 3.

The C III lines deserve our attention as well. Kafatos et al. (1980) observe λλ1176, 1247, 1908 in RW Hya, but they only measure the flux in λ1908. For RR Tel λλ1247, 1908, 2296 were identified, Penston et al. (1981) give fluxes for λλ1908, 2296. If the observed ratio of F(λ2296)/F(λ1909) $\approx$ 0.01 is uniquely due to collisional excitation then RR Tel emits the C III spectrum at $T_e \gtrsim 40000$ K (see Fig. 4 of Nussbaumer and Schild 1979). At this T_e, and $N_e \approx 10^{6}$ cm^{-3} the $^1P^o - {}^1S$ transition at λ1247 would not be observable as the calculated ratio is F(λ1247)/F(λ1908) < 0.001. However, as mentioned earlier, both λ1247 and λ2296 can be formed by recombination in the C IV region (Storey 1981); working with these lines therefore needs careful investigation in each case. Qualitative information is also provided by the absence of a line. Thus Altamore et al. (1981) suspect $T_e \approx 40000$ K, $N_e > 10^{10}$ cm^{-3} for Z And. For these conditions an unreddened ratio of F(λ2296)/F(λ1909) $\gtrsim$ 0.1 is expected; the scientific advantage of setting observational limits to that ratio is thus obvious. If the λ1176 multiplet was not placed in the low sensitivity range of IUE, it could help to verify our models as well.

At this stage I want to appeal to those taking spectra in the visual range. Qualitative description of temporal changes in the symbiotic objects are now clearly insufficient, we need calibrated spectra that give us fluxes in [energy/(time surface)]. Thus the spectrum of HM Sge as published by Blair et al. (1981) can be directly compared with IUE spectra from the same object; coverage down to the ultraviolet cutoff would of course add even more value.

We must admit that our knowledge about the nature of symbiotic objects is at present on the level of inspired guesswork. Whether some type of stellar corona has to be accomodated is not a futile speculation since X-ray radiation has been detected in symbiotic stars. If an emitting region with $T_e \approx 10^{6}$ K exists we might also expect coronal lines to appear in the IUE range. A list of coronal lines as observed in the sun between 1000 Å and 3000 Å has been published by Sandlin et al. (1977) and Sandlin and Tousey (1979); you might want to check your spectra against these lists. R Aqu may serve as an example. Zirin (1976) reports a detection of the Fe XIII $3s^2 3p^2\ {}^3P_0 - {}^3P_1$, ${}^3P_1 - {}^3P_2$ transitions at λλ10747, 10798. If these transitions should still be seen, then we could also expect the ${}^3P_1 - {}^1D_2$ λ2579 line which has been seen by Sandlin et al. (1977) in the solar spectrum.

4. LINE PROFILES

Apart from the ionisation structure, the radiation and electron temperatures, the particle density and the elemental abundances, we are also interested in the geometrical and dynamical configurations of our pets. Here the shapes of the emission lines hold a clue. In Figure 4 high resolution IUE spectra of C IV λλ1548, 1551 are shown. It is usually a strong doublet, and features which are real and not just instrumental noise should appear on both components.

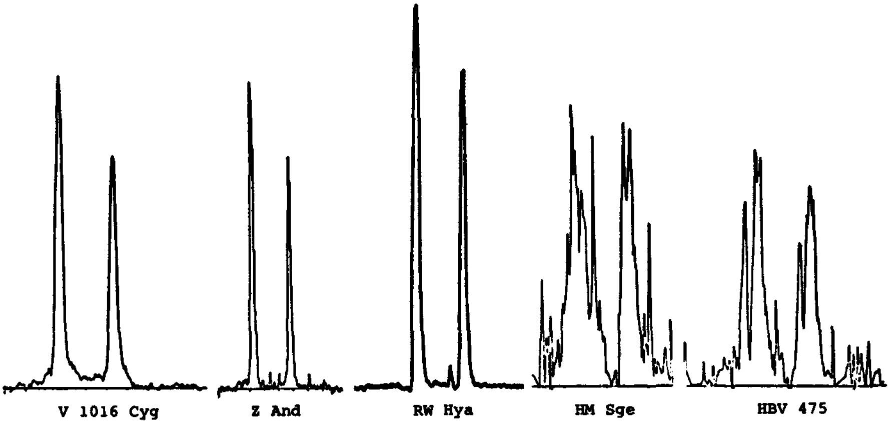

Figure 4. Line shapes of the C IV doublet at λλ1548, 1551

In Z And, V 1016 Cyg, and RW Hya the profiles are approximately symmetrical and a spherically symmetrical model can certainly be advocated. The profiles are much more complicated in HM Sge and even more so in HBV 475. Are the profiles of HM Sge and HBV 475 composed of several emission components, or are absorption lines eating into broader emission lines? In addition to the absorption feature at the rest wavelengths seen in HBV 475, I want to draw attention to an emission red shifted by ∿ 1 Å in both HM Sge and HBV 475. Is this a sign of a particle jet leaving those objects, away from us at v ≥ 190 km/s, or does it originate from mass transfer in a binary system, or do we observe double star systems with C IV emission from both? Well, it is probably none of these, but an instrumental effect, at least it has been seen in some more symbiotic objects (though not in others) at exactly the same position, Z And shows it but neither V 1016 Cyg nor RW Hya. We cannot altogether rule our a physical explanation; P.J. Storey and myself are looking into the possibility of satellite lines of the type $2s(^2S)n\ell$ - $2p(^2P^o)n\ell$ being responsible for these lines.

A problem that becomes apparent when studying high resolution IUE spectra concerns the flux ratios $F(^2S_{1/2} - {}^2P^o_{3/2})/F(^2S_{1/2} - {}^2P^o_{1/2})$ within the C IV multiplet. Instead of the expected ratio of 2, the observation give 1.7 for V 1016 Cyg, 1.3 Z And, and 1.2 for RW Hya. Nussbaumer and Schild (1981) mention that interstellar absorption could offer an explanation. However, if it should turn out that other classes of emission objects, for example planetary nebulae, do not show that effect, then the interstellar explanation would probably have to be dropped.

5. CONCLUSION

In our quest for understanding symbiotic stars, emission lines are likely to play a key part. They can be interpreted in a straightforward way to find typical values for N_e and T_e, abundance determinations, however, are already more demanding. When calculating T* from recombination lines we usually assume that the ionising star emits as a black body. Results from such preliminary investigations may already tell us whether the emission lines are emitted in a gas with predominantly radiative or collisional ionisation. Emission line profiles may hold clues to relations between the stellar and nebular parts of the objects. These preliminaries will be necessary before refined models can be elaborated.

I suspect that we shall find widely differing conditions in different symbiotic stars. Thus RR Tel and V 1016 Cyg have both similar densities of $N_e \approx 10^6$ cm^{-3}, but whereas V 1016 Cyg emits the bulk of its emission lines at $T_e \approx 15000$ K the evidence from O III and C III lines is rather in favour of $T_e \approx 40000$ K for RR Tel; in Z And where the N III] and O IV] lines require $N_e \approx 10^{10}$ cm^{-3}, the strong C III] λ1909 combined with the absence of C III λλ1176, 2296 indicate $T_e < 30000$ K. I do not want to preempt later discussions but I feel that placing an astronomical object in the class of symbiotic stars is simply a declaration of ignorance. I therefore suggest that we slightly modify the definition of a symbiotic object by including a declaration of ignorance in the following way: A symbiotic star is an astronomical object with the following properties:

a) its spectrum shows the typical nebular emission lines combined with the spectrum of a cool star
b) on the time scale of years its luminosity shows variations which may attain several mag
c) it cannot be clearly classified as something else.

Point (c) does not form part of the standard definition (e.g., Boyarchuk 1975). I propose its addition with the intention of turning "symbiotic stars" into a transitory class. Our task then consists of solving the enigmas attached to each object and unveiling its true nature. The advent of IUE (International Ultraviolet Explorer) has opened new roads in this endeavour.

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DISCUSSION ON UV EMISSION LINES

Friedjung: The CIII temperature gives the temperature of the CIII region, but not necessarily of regions of higher ionization stages. Our model for Z And was probably oversimplified; lower ionization stages are probably photoionized by a warm continuum. The question is how the high ionization stages are formed; are they photoionized or formed by collisions in something like the solar transition region?

Nussbaumer: Friedjung has touched on an important point. CIII informs on regions where CIII is formed, and the physical conditions there might be different from the CIV region. One must even be cautious with different lines from the same ion. Thus in the 1908 and the 1176 or 2296 multiplets of CIII the essential contributions to the total strength may come from different regions.

Viotti: The permitted (1176...)over intercombination (1909 A) emission line ratio is quite sensitive to the presence of a (even largely) diluted hot radiation field because of the radiative excitation of the permitted lines which dominates over collisional excitation.

Nussbaumer: I agree that radiative excitation in allowed multiplets like CIII λ 1176 has to be taken into account in the kind of model you (Altamore et al. 1981) suggest for Z And; on the other hand it can be neglected in the model that Schild and I propose for V1016 Cyg.

Kwok: In an extended object like V1016 Cyg where the size exceeds one arcsec, there are certainly variations in temperature and density within the nebula. How sensitive is the line interpretation on the density/temperature structure?

Nussbaumer: You are right in principle, one has to allow for density and temperature structure. But if you intend to say that this is more important for an extended object than for a small one, then I disagree. As counter examples (which may both be relevant to symbiotic stars) I can cite the solar transition region where T_e and N_e change by a factor 100 over 1000 km, and planetary nebulae where they hardly change over vastly extended volumes.

Kafatos: I would like to emphasize that for intercombination lines - which are optically thin - one should use the absolute intensities as well as relative intensities in the multiplets. For example, for the CIII lines it makes a lot of difference as far as the emission measure is concerned, if the temperature is $\lesssim$ 30000K or if it is $\gtrsim$40000K-100000K. When one does this for objects like RW Hya, V1016 Cyg and Z And, one finds that indeed the temperatures are low ($\lesssim$20000K) characteristic of photoionization.

Nussbaumer: The absolute fluxes certainly contain important information. In our objects the intercombination lines should be optically thin. Thus if we have a reasonable knowledge of N_e and T_e we can immediately gain some rough knowledge on the size of the emitting region. The doubts you have about the model proposed for Z And might be answered by the authors of Altamore et al. paper.

Viotti: The discussion about the electron temperature will be continued by Friedjung in his review on models.

Houziaux: What is the dilution factor used in the ionization computations, and what is the importance of dielectronic recombination on intercombination lines at the electron densities of symbiotic stars?

Nussbaumer: For the calculation of Table 1 I took the semi-infinite shell model as used by Nussbaumer and Schild for V1016 Cyg. The exact value of the inner boundary is not crucial in the present context. Dielectronic recombination is unlikely to be crucial as excitation mechanism for the well observed intercombination lines. It may however be the principal mechanism for other lines; examples are given by Storey (1981, Mon. Not. 195, 27P).

Keyes: Do you include charge-exchange in your calculations?

Nussbaumer: They are included as far as they have been published.

Keyes: Are you aware of any atomic data (transition probabilities, collision strengths) for the short-wavelength component of the SiIII intercombination multiplet λ1884. This feature is present in Z And (Altamore et al. 1981), and atomic data would enable a direct determination of the electron density to be made.

Nussbaumer: There is a thesis by Nicolas at NRL where these atomic data are given. Burke has done a new calculation for the collision strength of the total $^1S - ^3P^o$ multiplet.