THE FORMATION OF OPTICAL CNO EMISSION LINES IN CATACLYSMIC VARIABLES

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ABSTRACT

Spectroscopic observations of CNO emission lines are presented for old nova systems, and possible excitation processes for the lines are considered. The Bowen fluorescence mechanism cannot generally be responsible for the strength of N III λ4640 because of the weakness of O III λ3429. Other CNO lines are observed which indicate that all of the lines are excited by resonance fluorescence of UV continuum radiation. Several nonfluorescent excited lines of carbon are also present in old novae, probably formed by recombination processes. The available data for the optical CNO lines suggest that non-solar CNO enhancements exist in quiescent novae, indicating that some of the binary systems may be evolved.

INTRODUCTION

The strongest emission lines observed in the optical spectra of cataclysmic variables are the hydrogen Balmer lines, He II λ4686, and He I triplet and singlet transitions. The strongest non-H or -He line is usually the N III - C III λ4640 - 50 complex. Its strength is variable from one object to another, and is frequently correlated with the intensity of the He II λ4686 line. The large intrinsic widths of the lines in most CVs cause the N III λ4640 and C III λ4650 multiplets to be blended, therefore the relative contributions of the N III and C III lines to the λ4645 feature are uncertain for most objects. In a few systems which have narrower lines or which have been studied at higher dispersions, the feature has been partially resolved to varying extents, and the λ4645 complex has consisted of comparable contributions from the N III and the C III. In HR Del (Hutchings 1979), DQ Her (Hutchings et al. 1979), and QU Car (Gilliland and Phillips 1982), for example, the dominant contribution appears to be from C III λ4650. On the other hand, in many CVs the strength of the N III λλ4097, 4103 multiplet, which must be emitted following emission of N III λ4640 since the 3d $^3P^o$ level has no other radiative avenue of decay (cf. Figure 1), and which is usually blended in the wings of Hδ, indicates that N III must make a dominant contribution to the λ4645 feature in these objects.

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The N III - C III complex is the most prominent emission from any of the CNO ions which occurs in the optical spectra of cataclysmics. No theoretical study of this or any other CNO emission has yet been made for nova systems. However, an analysis of the λ4645 feature in the spectra of X-ray binaries (XRBs) has been made by McClintock _et al._ (1975), motivated by the fact that λ4645 is consistently one of the strongest lines in the visible spectra of low-mass XRBs. Various mechanisms were considered for the formation of the λ4645 emission, and McClintock _et al._ concluded from models of the emitting region that it was due to N III λ4640, excited by the Bowen (1935) fluorescence mechanism. This conclusion was strengthened by spectroscopic observations of HZ Her by Margon and Cohen (1978), who found one of the emission lines involved in the Bowen fluorescence process, O III λ3444, to be present in the HZ Her spectrum with approximately the correct strength expected from fluorescence. Other than N III λ4640, the emission lines formed by the Bowen mechanism tend to be weaker than λ4640, and occur at wavelengths less than 3800 Å. Their detection in faint objects is not easy, and consequently little systematic follow-up study of their presence in interactive binaries has taken place, although Canizares _et al._ (1979) did tentatively report the presence of weak Bowen lines in several X-ray bursters. On the basis of these observational results and the theoretical work of McClintock _et al._, the prevailing opinion has been that the λ4645 emission in XRBs is predominantly N III, and its unusual strength is caused by the selective excitation of the Bowen process.

N III BOWEN FLUORESCENCE IN CATACLYSMICS?

Since CVs and low-mass XRBs are believed to be very similar types of systems, and have similar optical spectra, it is suggestive that Bowen fluorescence may occur in cataclysmics. The energy level diagrams for He II, O III, and N III shown in Figure 1 illustrate how the Bowen process works. If He II λ304 photons are trapped by high optical depth, they scatter many times. A wavelength coincidence exists between the He II λ304 line and lines of the $2p^2\ ^3P - 3d\ ^3P^o$ resonance multiplet of O III, such that repeated He II scatterings eventually produce absorption by O III. For each absorption of O III λ304, there is ∿ 1% probability that a 3d - 3p transition takes place, one of which is the O III λ3429 multiplet, rather than re-emission of λ304. A λ374 A photon is emitted following the 3d - 3p emission, and sufficient scattering of the λ374 resonance line can then lead to absorption by N III $2p\ ^2P^o - 3d\ ^2D$ λ374, which coincidentally has the same wavelength as the O III line. With each N III λ374 absorption, there is a 0.5% likelihood that N III λ4640 will be emitted instead of λ374. The net effect of the entire scattering process is that He II λ304 (Ly-α) photons are converted via O III transitions into N III λ4640 emission. The fluorescence mechanism requires (1) high resonance line optical depths to produce trapping of the line radiation so conversion to optical transitions can take place, and (2) densities which are sufficiently low such that collisional de-excitation of the levels does not occur.

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Conservation of photons in the scattering process imposes a limit on the relative intensities of the O III and N III lines which must be satisfied by Bowen fluorescence. Since escape of some resonance line photons must occur,

$$N(\text{OIII } \lambda 304) \geq N(\text{OIII } \lambda\lambda 3127,3429,2830) \geq N(\text{NIII } \lambda 374) \geq N(\text{NIII } \lambda 4640), \quad (1)$$

where $N = 4\pi J_\nu/(h c \nu)$ is the energy density of line photons. Using published transition probabilities (Wiese et al. 1966) which dictate the branching ratios for the O III λλ3127, 3429, and 2830 multiplets leads to the limit that J(O III λ3429) $\geq$ 0.5 J(N III λ4640) for excitation by the Bowen mechanism. Realistically, the O III multiplet should be stronger than the N III multiplet since the lower limit to the O III/N III flux ratio requires 100% efficiency of the entire fluorescence process. However, in planetary nebulae the maximum efficiency found for the conversion of He II λ304 to O III λ374 is only 30% (Seaton 1960; Kaler 1967). And there is probably an even smaller efficiency for conversion of O III λ374 to N III λ4640 because of the smaller optical depths of the O III resonance lines relative to that of He II Ly-α. Because of the large velocity gradients which gas in CVs possesses, which drive down line optical depths, it would be surprising if Bowen fluorescence were more efficient in interacting binary systems than it is in the nebulae.

As an observational check on the Bowen fluorescence mechanism, we have obtained spectral scans of cataclysmic variables extending down to 3400 Å in an attempt to detect the O III λ3429 multiplet in those systems in which the N III - C III λ4645 feature is present. A representative sample of objects observed with moderately good signal-to-noise in the blue is shown in Figures 2 - 5. All of the objects are CVs, old novae and nova-like variables, having easily detectable λ4645 lines. For most of the systems, the N III λλ4097, 4103 multiplet seems to be present, appearing as unresolved bumps in the base of the Hδ line, substantiating the contribution of N III λ4640 to the λ4645 feature in these objects. Based on the comparative strengths of N III λ4099 and N III - C III λ4645, an appreciable fraction of λ4645 is due to N III.

Several points may be made from the spectral scans in Figures 2 - 5. First, with the exception of the magnetic AM Her-type variable PG 1550+19, none of these CVs shows O III λ3429 clearly. There is a strong suggestion of it in DQ Her, but the line there is probably too narrow to be real, and it does not appear on other scans of DQ Her. From the relative strengths of the λ4645 emission and (the upper limits to) O III λ3429 in these objects, the Bowen fluorescence mechanism can therefore essentially be ruled out as the cause of N III λ4640. Second, other CNO lines are present in the spectra of these CVs, and they have been identified in the scans. These lines are O III λ3712, C II λ4267, and C IV λ5805. The C II line occurs frequently in the old novae, and the C IV line is somewhat less common. Although the spectrum of BT Mon in Figure 2 does not extend out to λ5800 Å, the

C IV λ5805 line is present in other scans we have of this system (cf. Williams and Ferguson 1982, Figure 4).

An important question to be addressed concerning the spectra is: what conditions produce these lines, and what can be learned about CVs from the line strengths? The fact that certain CNO lines have intensities comparable to the H and He lines suggests that a selective excitation mechanism may be operative; however, we are convinced from the general weakness of O III λ3429 in objects which have prominent λ4645 that Bowen fluorescence is usually not responsible for the strength of N III λ4640. We suspect that the same conclusion may also apply to many of the low mass X-ray binaries.

CONTINUUM FLUORESCENCE OF CNO LINES

There is a similarity shared by the O III λ3712, N III λ4640, and C IV λ5805 lines which we believe to be significant: all of these multiplets have upper levels which are connected to the ground states of the respective ions by strong resonance transitions. That is, each of these lines is capable of being excited by fluorescent excitation. However, selective line excitation such as the Bowen mechanism is unlikely to work for all of these transitions since they are all excited, or pumped, by different wavelengths. In fact, the Bowen mechanism does not even appear to be responsible for the N III line. Instead, we propose here that the above multiplets are formed in cataclysmics by continuum fluorescence, i.e., photoexcitation of the upper levels by an extension of the strong UV continuum that CVs have been observed to have with the IUE satellite. It is unlikely that any other excitation process would produce these three particular multiplets so strongly in comparison with other CNO transitions. For example, these are not lines which would be excited by the recombination process since electron recapture tends to preferentially populate levels with high angular momentum. Similarly, collisional excitation of these transitions would also cause greater population of other transitions having lower excitation potentials, but which are not observed. Thus we believe the evidence favors continuum fluorescence for the excitation of λ3712, λ4640, and λ5805.

In order to check on our assumption of continuum fluorescent excitation, we have determined from the energy level diagrams of CNO ions (Bashkin and Stoner 1975) all those optical transitions which could occur from this process and which might be expected to be present in the spectra of CVs. The situation in which fluorescent excitation occurs involves three levels, one of which is the ground state of the ion, and is schematically depicted in Figure 6. Absorption of continuous radiation at wavelength λ_{12} takes place by a resonance line, always in the UV for CNO ions. Following each 1→2 UV absorption, there is a finite probability, typically ∿ 1% depending on the relative transition probabilities, that emission of a subordinate optical transition 2→3 may occur rather than re-emission of the UV resonance line. The emissivity of the optical line can be written as

$$j_{23} = N_2 A_{23} \frac{h\nu_{23}}{4\pi} , \quad (2)$$

where N_2 is the number density of ions in level 2. In a steady-state situation, the equilibrium population of level 2 is determined by the rate of resonance absorptions into the level and the rate of spontaneous transitions out, i.e.,

$$N_1 \, B_{12} \, J_{\nu_{12}} = N_2 \, (A_{21} + A_{23}). \quad (3)$$

The stimulated Einstein coefficient B_{12} is related to the spontaneous transition probability A_{21} by the relation $B_{12} \propto A_{21}\lambda_{12}^3 \, g_2/g_1$, where the g_i are the statistical weights of the levels. Substituting eqn. (3) into (2) therefore gives for the emissivity of a line excited by fluorescence,

$$j_{23} \propto N_1 \, J_{\nu_{12}} \frac{\lambda_{12}^3}{\lambda_{23}} \, A_{23} \, \frac{g_2}{g_1} , \quad (4)$$

where we have assumed that $A_{21} >> A_{23}$, as is usually the case when $2 \rightarrow 1$ is a UV resonance line and $2 \rightarrow 3$ is an optical transition. In most situations N_1 may be taken to be the ion density, and therefore the intensity of a line excited by fluorescence is directly proportional to the ion abundance, the mean intensity of exciting radiation at the UV pumping frequency, and atomic constants of the transitions. We have compiled a list of the strongest CNO lines capable of being photo-excited by UV continuum radiation, and give them in Table 1 together with relevant atomic data. The final column gives the relative emission strengths of the lines, assuming all ions to have the same abundance and the UV continuum radiation to have a flat distribution.

The observed lines excited by continuum fluorescence in CVs originate in a region where the CNO are doubly and triply ionized. This region must have a lower density than the accretion disk in order for radiative and scattering processes to dominate over collisions, because LTE conditions prevail in the disk (Williams and Ferguson 1982), and therefore the CNO lines are probably not formed in the main part of the disk. On the other hand, it is unlikely that they originate very far from the central UV continuum-emitting region of the disk since a larger flux of radiation enhances the formation of the lines. Thus, the optimal environment for the line formation is in a lower density "chromospheric" region immediately above and below the disk, or in an outflowing wind in the vicinity of the disk.

It should be noted that the multiplets O III λ3429, O III λ3712, N III λ4640, and C IV λ5805 which have been observed in CVs, are among the strongest ones expected from fluorescent excitation of these ions. Given the presence of these lines, the following lines from these same elements might also be expected to be present on the basis of the information in Table 1: C III λ5250, N IV λ6381, and O IV λ3409. None of these lines has been detected in any of our scans, although the N IV multiplet is not expected to be very strong. Their absence may be due to several factors, including (a) the ionization may be sharply peaked such that C^{+3}, N^{+2}, and O^{+2} are much more abundant than other ionization stages where the fluorescence occurs, or (b) the computed transition probabilities for the unseen lines may have been overestimated. An additional possibility, that the continuum flux responsible for exciting the unobserved λλ3409, 5250, 6381 lines is substantially less than that pumping the observed λλ3429, 3712, 4640, 5805 lines is very unlikely since most of these transitions are excited by resonance lines having similar wavelengths, around λ300 Å.

An example of the very useful type of information about cataclysmics that is potentially available from analysis of the CNO emission lines comes from applying eqn. (4) to the observed fluorescence excited lines under the simplistic assumptions that the lines are formed together in the same region and that the UV continuum flux is constant over the ∿ 75 Å interval from 300 - 375 Å that serves to excite the lines. The abundance ratios of the ions, by number, are related to the line fluxes by

$$\frac{C^{+3}}{N^{+2}} = 2.1 \ \frac{F(\lambda 5805)}{F(\lambda 4640)} \quad , \tag{5}$$

$$\frac{N^{+2}}{O^{+2}} = 1.3 \ \frac{F(\lambda 4640)}{F(\lambda 3712)} \quad . \tag{6}$$

For CP Pup, where the intensities are roughly in the ratio F(λ5805)/F(λ4640)/F(λ3712) $\simeq$ 1/2/2, allowing for some contribution of C III to λ4645, the deduced ion abundances are $C^{+3}/N^{+2} \simeq 1$ and $N^{+2}/O^{+2} \simeq 1$. If these ions are the predominant ones of CNO in the emitting regions, then C $\simeq$ N $\simeq$ O, which is non-solar and may be evidence for evolved gas. More extreme examples of non-solar, evolved CNO abundances for the emitting gas may be indicated for objects such as RR Pic, which have moderately strong N III λ4640 with no detectable C IV or O III lines. Presumably, the emitting gas is situated sufficiently far out in the potential well of the white dwarf that it represents mass lost from the secondary star rather than gas somehow ejected from the degenerate companion.

NON-FLUORESCENT EXCITATION OF CNO LINES

With the exception of C II λ4267 and C III λ4650, the optical CNO emission lines observed in cataclysmics can be explained in terms of fluorescent excitation. However, neither λ4267 nor λ4650 couple directly to the ground states of C II or C III via electric dipole resonance lines, consequently these lines must be excited by a

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different process. Both lines have moderately high excitation potentials (> 20 eV), and thus are unlikely to be strongly collisionally excited. C II $\lambda 4267$ is expected to be the most intense optical line in the recombination spectrum of C II (Williams 1982) because electrons recaptured to most of the high (n, 1) levels cascade through $\lambda 4267$ on the way to the ground state. On the other hand, the upper level of C III $\lambda 4650$ is not likely to be heavily populated by electron recapture in comparison to a number of other optical transitions in the C III spectrum. Thus, we encounter a dilemma in trying to explain the strength of $\lambda 4650$ in CVs: both collisional excitation and recombination should produce other lines with greater strength than $\lambda 4650$, but which are not observed in the spectra of catalysmics. Apparently, some selective excitation mechanism is operative for this line. This dilemma is not unique to the spectra of CVs, but appears to be a general situation when C III $\lambda 4650$ is observed in emission. For example, in their investigation of the emission spectra of Wolf-Rayet stars, Castor and Nussbaumer (1972) considered the excitation of a number of levels of C III from a variety of processes, and yet still failed to produce the observed $\lambda 4650$ intensity in their models by factors of 1 to 2 orders of magnitude. The large discrepancy they found between their calculations and the observations led them to suggest that some process involving the continuum of C III, such as dielectronic recombination, populates the 3p $^3P^o$ level and causes $\lambda 4650$ to be enhanced. We suspect this same situation occurs in cataclysmics and causes C III $\lambda 4650$ to contribute to the N III - C III $\lambda 4645$ feature.

The excitation of C II $\lambda 4267$ is more straightforward, almost certainly involving only electron recapture processes. There is a possibility of dielectronic recombination populating the $2s^2 4f\ ^2F^o$ upper level of $\lambda 4267$ by radiative decay from the 2s2p4f ^2D, ^2F, ^2G autoionizing levels that lie $\sim$ 3 eV above the C II ionization limit. Storey (1981) has calculated the reaction rates and shown that emission of $\lambda 4267$ will be enhanced over the 2-body recombination rate for temperatures $\geq 2 \times 10^4$ K. Assuming the chromospheric temperatures in CVs to be less than this value, the presence of $\lambda 4267$ in the spectra of old novae with the characteristic flux seen in these systems, of the order of $\geq 10\%$ of the Hβ flux, may require a rather high C/H abundance in the emitting gas. With Hβ also formed by recombination in the same region as $\lambda 4267$, the relation between line strengths and ion abundances is

$$\frac{F(\lambda 4267)}{F(H\beta)} = \frac{N(C^{+2})}{N(H^{+})} \; \frac{\alpha(\lambda 4267)}{\alpha(H\beta)} \; \frac{4861}{4267} , \qquad (7)$$

where the ratio of the effective line recombination coefficients has been computed to be $\alpha(\lambda 4267)/\alpha(H\beta) = 8.2$ (Seaton 1978). The resulting abundance is $C^{+2}/H^{+} \cong 10^{-2}$ in the old nova systems in which the C II line has been observed.

SUMMARY

The N III - C III λ4645 line is the strongest optical emission feature from CNO ions in cataclysmic variables, and there is evidence that both N III and C III contribute to the line. The mean wavelength of the feature usually falls between the wavelengths of the two multiplets. In some objects the feature appears resolved into individual N III and C III components, and in many CVs where the feature is relatively strong, the blending of N III λλ4097, 4103, which is emitted following λ4640 emission, with Hδ is clearly evident in the base of the Balmer line.

The weakness or absence of O III λ3429 emission in old novae in which N III is present rules out the Bowen process as the excitation mechanism. Instead, the presence of other emission lines such as O III λ3712 and C IV λ5805, which can be excited by fluorescence at wavelengths other than those involved in the Bowen mechanism, is strong circumstantial evidence that all of these lines are emitted following resonance scattering of continuum radiation. The relative intensities of the lines in several systems indicate comparable abundances for the C, N, and O. Even greater departures from solar abundances are indicated for objects like RR Pic which show N III λ4640 but not O III, suggesting $N/O > 1$. Such systems may have nuclear-processed gas being transferred from an evolved secondary onto the degenerate dwarf companion.

Further evidence for the presence of evolved gas in cataclysmics may come from the existence of C II λ4267 and C III λ4650 emission. These lines are not directly excited by fluorescence, and their observed strengths suggest a high abundance of carbon because the effective reaction rates for their formation, involving electron recombination, are smaller than those for fluorescent excitation.

Several problems remain concerning the interpretation of the optical CNO emission in CVs. First, the absence of C III λ5250 in objects in which C II λ4267, C IV λ5805, and N III λ4640 emission are present requires explanation. The λ5250 line is pumped by UV wavelengths very near those exciting the C IV line, and its transition probability is such that whenever the C II and C IV lines are observed, the abundance and ionization of carbon should be optimum for λ5250 to be emitted with an intensity comparable to that of C IV λ5805. The computed transition probability for λ5250 may simply be in error. Or perhaps the C II recombination line is formed in a larger, separate region from the fluorescent-excited C IV line, in which case the region where carbon is doubly ionized would be more distance from the source of exciting continuum radiation, causing λ5250 to be much fainter than λ5805. Second, any analysis of CNO emission in close binaries should also include the UV lines which can be observed with the IUE satellite. There is a good possibility that the optical and UV lines are formed together, since the lines observed in both spectral regions require a scattering medium. Analyses of UV emission-line

TABLE 1

OPTICAL CNO LINES EXCITABLE BY RESONANCE FLUORESCENCE

Ion	Multiplet	λ_{12}(A)	A_{23} (10^8 sec^{-1})	$10^4 A_{23} g_2 \lambda_{12}^3/(g_1 \lambda_{23})$
C II	λ3920 3p $^2P^o$ -4s ^2S	636	1.87	4.1
	λ4638 4p $^2P^o$ -6d ^2D	530	0.030[a]	0.16
	λ6259 4p $^2P^o$ -5d ^2D	560	0.021[a]	0.10
	λ7234 3p $^2P^o$ -3d ^2D	687	0.45	3.4
C III	λ3170 4s ^1S -5p $^1P^o$	291	0.32	0.75
	λ5250 4d ^1D -5p $^1P^o$	291	0.52	0.73
	λ8500 3s ^1S -3p $^1P^o$	386	----	----
C IV	λ4786 5d ^2D -6p $^2P^o$	212	0.34	0.20
	λ5805 3s ^2S -3p $^2P^o$	312	0.32	0.50
C V	λ3479 2s ^1S -2p $^1P^o$	40	0.16	0.001
N II	λ4794 3p ^3D -3d $^3D^o$	534	0.36	1.9
	λ5001 3p ^3S -3d $^3P^o$	530	0.75	2.2
	λ5938 3p ^3P -3d $^3D^o$	534	0.56	2.4
N III	λ4640 3p $^2P^o$ -3d ^2D	374	0.57[a]	1.07
N IV	λ6381 3s ^1S -3p $^1P^o$	247	0.19	0.13
N V	λ4609 3s ^2S -3p $^2P^o$	209	0.41	0.24
O II	λ3292 3p $^4P^o$ -4s ^4P	419	0.85	5.7
	λ3754 3p $^4S^o$ -4s ^4P	419	0.26	1.5
	λ4152 3p $^4P^o$ -3d ^4P	430	1.01	5.8
O III	λ3429 3p ^3P -3d $^3P^o$	304	0.79	0.65
	λ3712 3p ^3P -3d $^3D^o$	306	1.10	1.4
O IV	λ3409 3p $^2P^o$ -3d ^2D	238	1.15	0.76
O V	λ5114 3s ^1S -3p $^1P^o$	172	0.25	0.075

[a]Transition probabilities from Kurucz and Peytremann (1975). All others from Wiese *et al.* (1966).

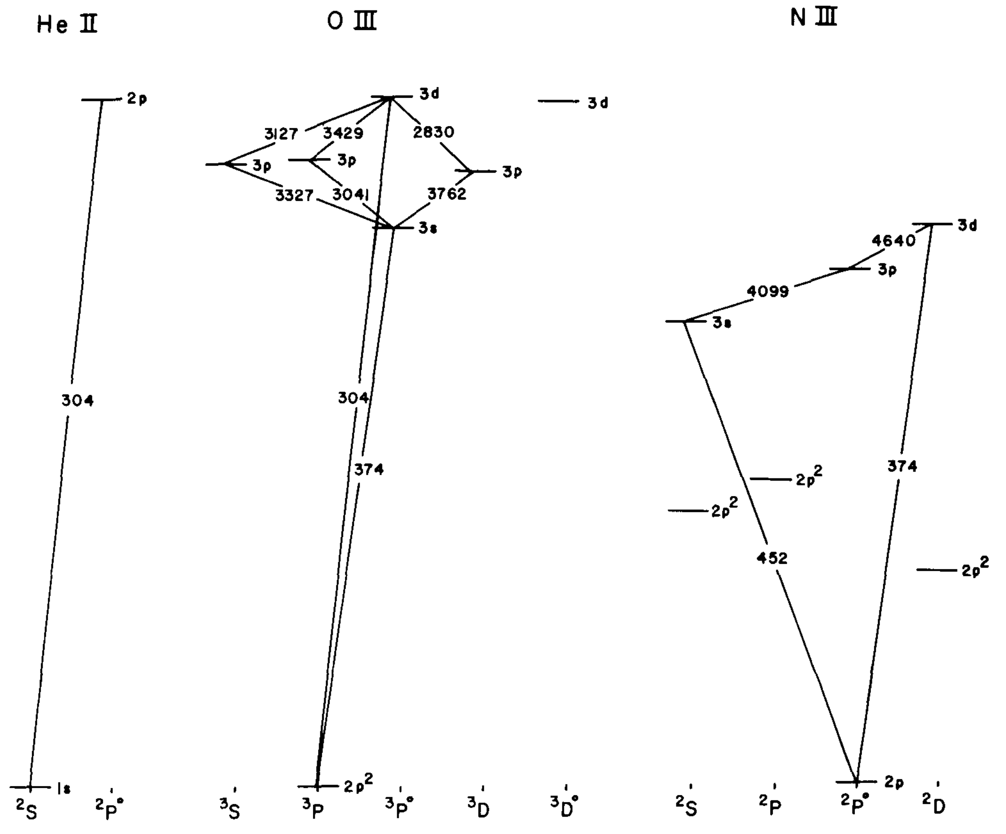


Figure 1 -- Partial energy level diagrams for He II, O III, and N III showing the transitions involved in the Bowen fluorescence mechanism.

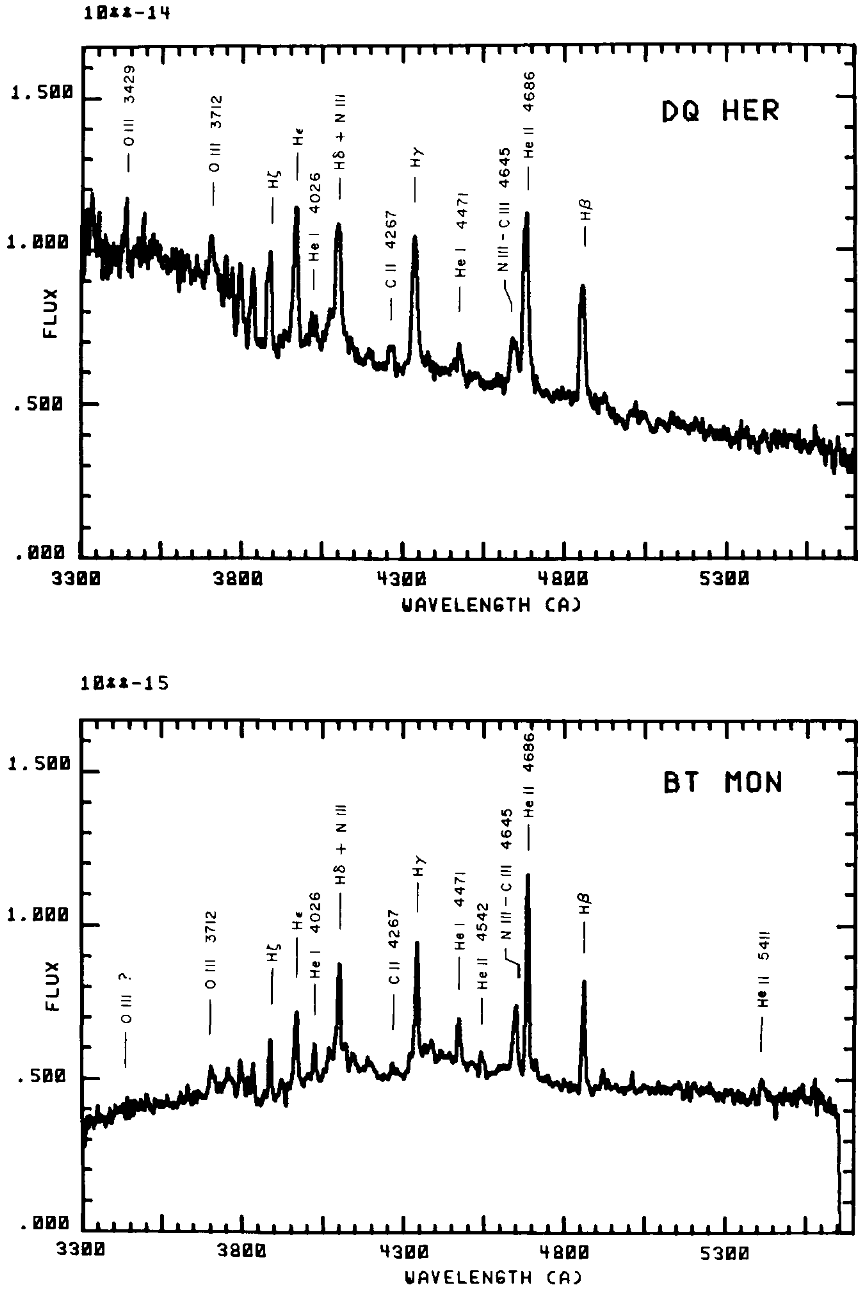
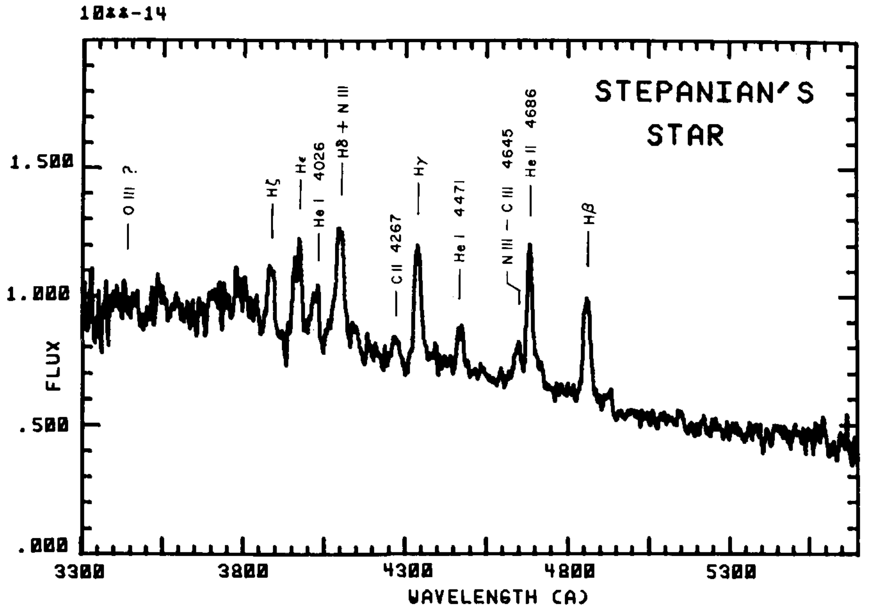


Figure 2 -- Spectral scans of the old novae DQ Her and BT Mon obtained with the Steward Observatory 2.3 m telescope and intensified Reticon scanner. The monochromatic flux F_λ is in units ergs/(cm^2 sec A).



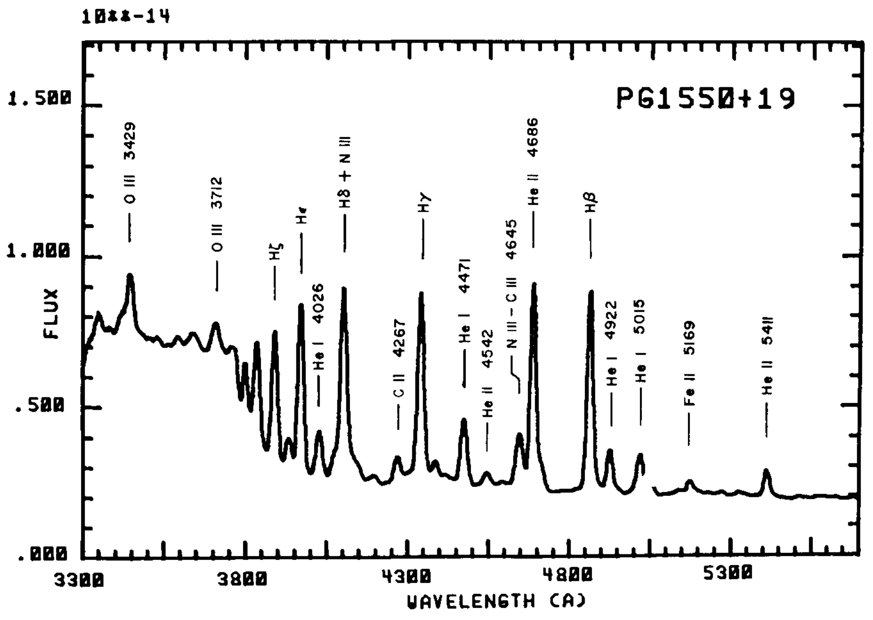


Figure 3 -- Spectral scans of the nova-like variables Stepanian's Star and PG 1550+19, obtained with the Steward Observatory 2.3 m telescope.

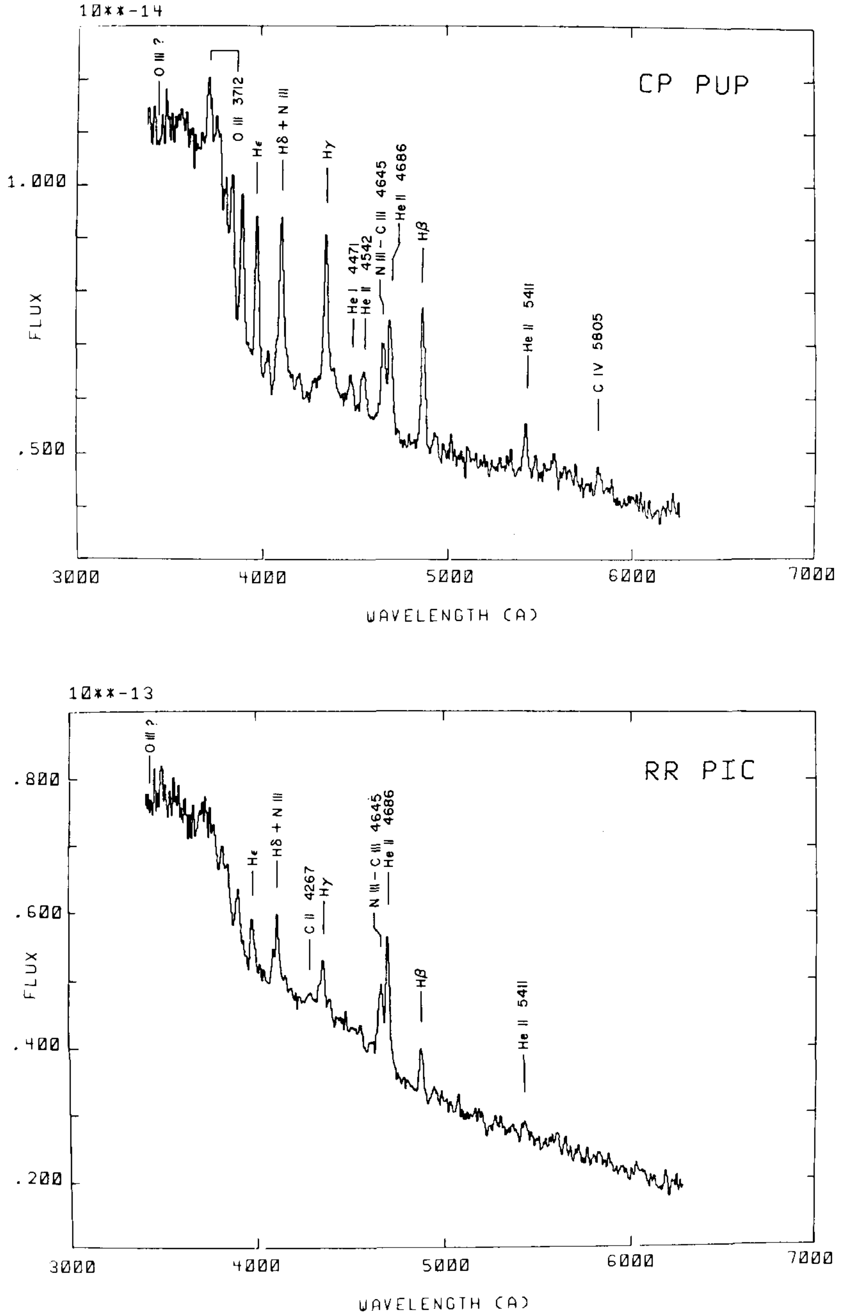


Figure 4 -- Spectra of the old classical novae CP Pup and RR Pic, obtained with the Cerro Tololo 4 m telescope and SIT Vidicon in April 1982. Units of flux are the same as Figures 2 and 3.

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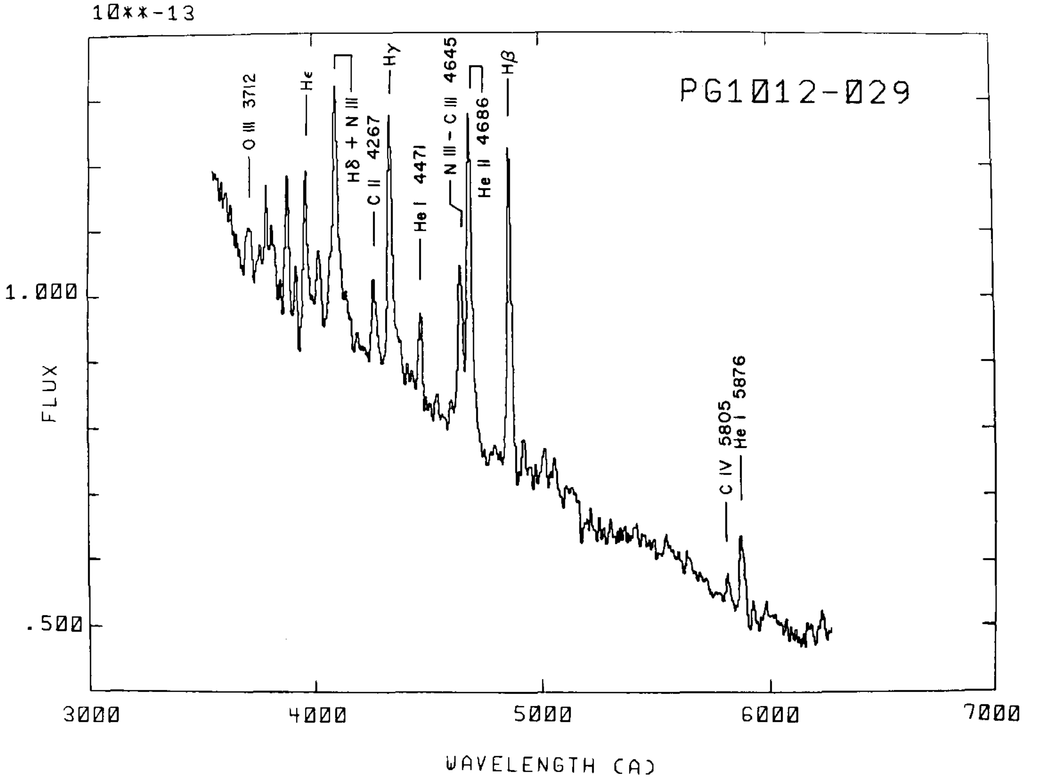

Figure 5 -- Spectral scan of the nova-like variable PG 1012-03, obtained with the Cerro Tololo 4 m telescope and SIT Vidicon.

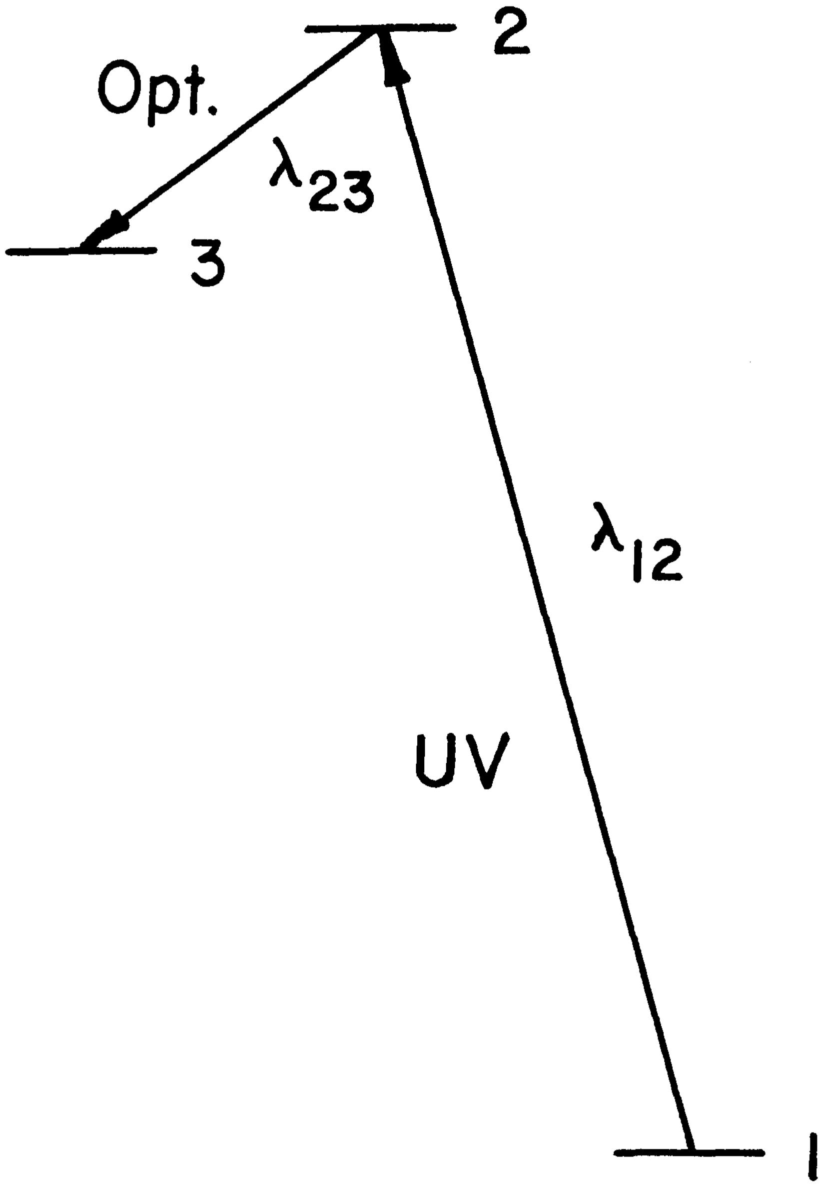

Figure 6 -- Schematic energy level diagram for transitions excited by resonance fluorescence of continuum radiation.

spectra have been performed for AE Aqr (Jameson et al. 1980) and V603 Aql (Ferland et al. 1982), but they have not shown clear evidence in these two systems for the magnitude of non-solar CNO abundances that our optical line interpretation has indicated for some CVs in the present investigation. The ultimate resolution of the question of the evolutionary status of interacting binaries should eventually result from the combined analysis of both optical and UV emission lines in representative systems.

REFERENCES

Bashkin, S., and Stoner, J. O. 1975, Atomic Energy Levels and Grotrian Diagrams (Amsterdam: North-Holland).

Bowen, I. S. 1935, Ap. J., 81, 1.

Canizares, C. R., McClintock, J. E., and Grindlay, J. E. 1979, Ap. J., 234, 556.

Castor, J. I., and Nussbaumer, H. 1972, MNRAS, 155, 293.

Ferland, G. J., Lambert, D. L., McCall, M. J., Shields, G. A., and Slovak, M. H. 1982, Ap. J., 260, in press.

Gilliland, R. L., and Phillips, M. M. 1982, Ap. J., in press.

Hutchings, J. B. 1979, Ap. J., 232, 176.

Hutchings, J. B., Cowley, A. P., and Crampton, D. 1979, Ap. J., 232, 500.

Jameson, R. F., King, A. R., and Sherrington, M. R. 1980, MNRAS, 191, 559.

Kaler, J. B. 1967, Ap. J., 149, 383.

Kurucz, R. L., and Peytremann, E. 1975, A Table of Semiempirical gf Values, Smithsonian Astrophys. Observ. Special Report No. 362.

Margon, B., and Cohen, J. G. 1978, Ap. J. (Letters), 222, L33.

McClintock, J. E., Canizares, C. R., and Tarter, C. B. 1975, Ap. J., 198, 641.

Seaton, M. J. 1960, Repts. Prog. Phys., 23, 313.

Seaton, M. J. 1978, in IAU Symp. No. 76: Planetary Nebulae, ed. Y. Terzian (Dordrecht: Reidel), p. 131.

Storey, P. J. 1981, MNRAS, 195, 27P.

Wiese, W. L., Smith, M. W., and Glennon, B. M. 1966, Atomic Transition Probabilities (Washington: USGPO), Vol. 1, NSRDS-NBS 4.

Williams, R. E. 1982, Ap. J., 261, in press.

Williams, R. E., and Ferguson, D. H. 1982, Ap. J., 257, 672.

DISCUSSION FOLLOWING R. WILLIAMS' TALK

EVANS: The ejecta abundances, how are these likely to be effected by the fact that you may have condensations of graphite grains and secondly is there any prospect of determining whether there is any change in carbon abundance before and after the nebular stage?

WILLIAMS: First of all, grain formation may be relevant, we know certainly in FH Ser that there was grain formation, just from the infrared within a month after the outburst. What that would tend to do is to cause the actual CNO to hydrogen abundances to be greater than those we talk about here, in which case we should perhaps qualify our statement about the CNO to hydrogen abundances after the outburst being similar to those before. It is an order of magnitude statement in any event. I cannot say anything definitely because I have not observed in the infrared but certainly it is something that is potentially important. About the second part of your question, Ferland and I are working on that problem right now, perhaps you are aware of the paper he wrote with Jim Truran that suggested that the conventional analysis of the spectra of DQ Her since its outburst indicates that the carbon to hydrogen abundance has changed, we now think that perhaps that conclusion can be explained in terms of conventional nebular analysis rather than dust formation but that doesn't rule out dust formation.

KING: Doesn't your fluorescence mechanism rather tightly constrain the continuum in that it's got to be able to lift the thing from the ground state to the third level, but not ionize it?

WILLIAMS: In fact, it has to ionize it also, because I think that is probably what is producing the OIII and the NIII. This whole fluorescence process is predicated on the fact that you have a scattering situation and that doesn't occur in the conventional disk model because the densities are too high, therefore I suspect that these lines are not coming from the inner part of the disk where the hydrogen and helium lines are coming from, but from some photoionized chromosphere or a wind or something like that, in which case I would say that the continuum is what is producing the ionization and also giving the fluorescence.

KING: Do you have to arrange it very cunningly so that you don't kill the element you are actually using?

WILLIAMS: No, it is not different from any other photoionization calculation.

WARNER: This morning we saw a spectrum of BV Cen which had a very well developed solar type spectrum, in other words, the secondary could be seen, is there any evidence of CH or CN enhancement in that spectrum, do you know?

WILLIAMS: I don't know if one sees it.

WARNER: There is the possibility for an independent witness for your story.

BIANCHINI: Is it possible that collisional excitation, with the interstellar medium, plays a role in favour of certain lines?

WILLIAMS: Only for GK Per. Because that is the only nova shell spectrum that indicates an extremely hot gas, the electron temperatures are 40000°K. It has a spectrum that looks just like a supernova remnant and it is the only really asymmetric shell, so the case can be made for GK Per.

NETZER: Surely the equation you used is only for the optically thin case, is that procedure correct? You are talking about a resonant line.

WILLIAMS: It is valid for optically thin optical transitions and optically thin or thick UV.

NETZER: You can take the number of continuum photons, you can easily extrapolate from the IUE data and see if the number you get there is about the same number you expect to get in the optical by conversion.

WILLIAMS: Yes, that is a good point.

NETZER: If you do explain the CII line by recombination, then have you done the same exercise for the other lines assuming that you know roughly the N and O abundance? because I would expect them to have about an equal strength.

WILLIAMS: Not quite. I have done something else, and that is, assuming that you have recombination, I have computed what intensities you would expect for those lines relative to other lines in the same ion, CIV 5805 would be weaker than some other CIV lines if it were due to recombination because they are not high angular momentum states, so it was on that basis that I have ruled it out. I should say that there is a possibility that 4267 may have a di-electronic recombination contribution.