THE ASTROPHYSICAL JOURNAL, 228:482–490, 1979 March 1

SPECTROPHOTOMETRY OF FILAMENTS SURROUNDING NOVA RR PICTORIS 1925

R. E. WILLIAMS*
Steward Observatory, University of Arizona

AND

J. S. GALLAGHER*
Department of Astronomy, University of Illinois
Received 1978 August 3; accepted 1978 September 14

ABSTRACT

Spectral scans of faint filaments surrounding the slow nova RR Pic have been obtained with the CTIO 4 m telescope, using the Tololo vidicon spectrometer. The spectra are similar to those of very high-excitation planetary nebulae, in addition to having prominent [Fe v] emission. Available evidence indicates that the nebular condensations are ionized by radiation from RR Pic. Ionization calculations of the gas show that the spectra can be produced by photoionization, and that the abundances of He, N, and probably also Ne are enhanced. Conditions in the RR Pic filaments are contrasted with those in the shell of the slow nova DQ Her.

Subject headings: nebulae: abundances — nebulae: general — spectrophotometry — stars: individual — stars: novae

I. INTRODUCTION

RR Pic is an eclipsing binary, old nova system which erupted in 1925 and reached a maximum brightness of $m_v = 1.2$ during the outburst. Its light curve was typical for a slow nova, achieving several postmaximum peaks which came within 1 mag of maximum and having a slow rate of decline. The spectral development of the nova from the time of outburst until some years afterward has been described in an extensive study by Jones (1931). The most notable feature of the spectrum during the period of decline was the prominence of numerous Fe lines, in a number of different ionization stages, particularly in the emission spectrum during the "nebular" phase of the nova (Payne-Gaposchkin 1957). In this regard, RR Pic was similar to the slow nova RR Tel (Thackeray 1977).

Several years after the outburst, nebular filaments of gas were initially reported around RR Pic by van den Bos and Finsen (Jones 1931), who observed two bright knots on opposite sides of the stellar remnant. They studied visually the brightness and positions of the filaments over a period of 3 years, and observed the knots to be moving away from RR Pic along lines having position angles of approximately 70° and 230°, respectively, with a total separation of 2″ in 1931. McLaughlin (1936, 1960) based his determination of the distance to RR Pic (480 pc) on these observations of the angular expansion of the knots.

We are unaware of any further study or of any photographs of the envelope around RR Pic; we therefore asked Dr. J. Graham to obtain a red photograph of the nova with the CTIO 4 m telescope, so that we could determine the present structure of the shell in order to study it spectroscopically. The resulting photograph of RR Pic, obtained on 1977, March 11 at the prime focus in 3″ seeing on a baked 098–04 emulsion with an RG-610 filter (effective response: 6100–7000 Å) is shown in Figure 1. The photograph shows that the envelope now consists of filamentary extensions along two lines through the nova, lines which are roughly perpendicular to each other. The position angles we measure for the filaments are 62° (242°), which is shown as line AA in Figure 1, and 154° (334°). The extent of the filaments is about 23″ along line AA, and 18″ in the perpendicular direction. From these dimensions of the shell, and an assumed isotropic expansion velocity of 400 km s^{-1} (Payne-Gaposchkin 1957), the distance to RR Pic should lie in the range from 380 to 490 pc, in good agreement with McLaughlin's earlier measurement. The condensations along AA appear to be symmetric about the nova remnant, and are more isolated from it and fainter than the other extension. The knots observed by van den Bos and Finsen can probably now be identified as the filaments seen along line AA, because of the similarity in the position angles. If they continued to move away from each other at constant velocity, the knots seen earlier would now be separated by about 20″, in agreement with the present separation.

II. OBSERVATIONS

As part of a continuing program to study physical conditions in the ejecta of novae, spectral scans of the filaments around RR Pic were obtained in 1978 January, using the Tololo SIT vidicon spectrometer

* Visiting Astronomer, Cerro Tololo Inter-American Observatory, which is operated by AURA, Inc., under contract with the National Science Foundation.

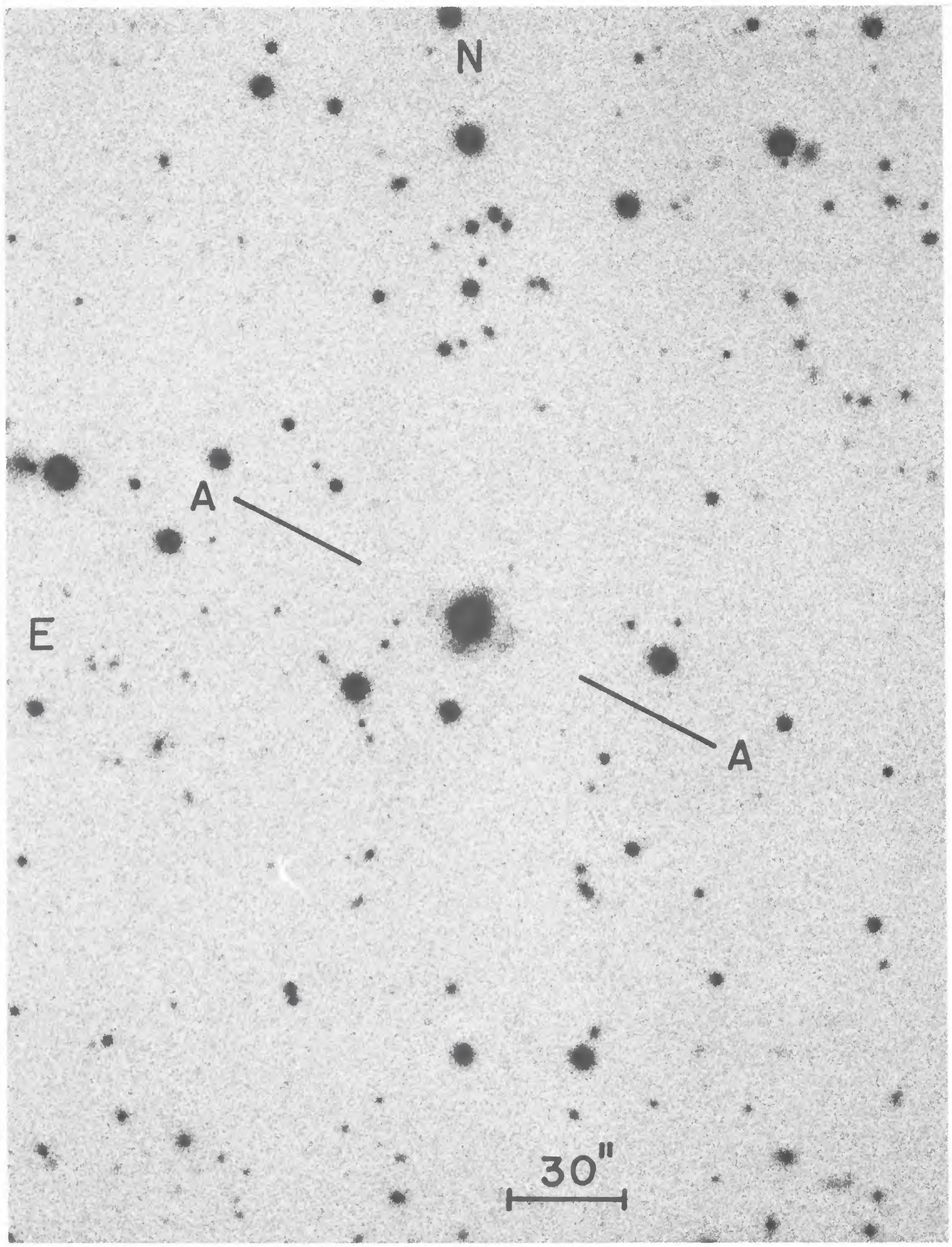

FIG. 1.—Red photograph of RR Pic showing faint filaments of ejected gas, obtained by J. Graham with the CTIO 4 m telescope. Spectral scans were obtained with the spectrograph slit oriented along line AA.

attached to the CTIO 4 m telescope. A slit width of 3".6 was used, and a grating-camera combination which provided a spectral coverage of approximately 1500 Å with a resolution of about 9 Å. Data were obtained in the blue and red spectral regions with the spectrograph slit oriented along line AA. The spectra were untrailed, and a wedge-shaped decker was inserted over the center of the slit which blocked the light of the star in order to minimize the contamination of the spectra of the faint filaments by scattered starlight within the spectrograph.

The data were reduced by standard procedures using the Tololo software package (Osmer and Smith 1976, 1977) in order to give monochromatic flux versus wavelength for each vidicon scan line. At the Cassegrain focus, each individual scan line perpendicular to the dispersion corresponds to a region of sky roughly 1" in extent. Wavelength calibration was obtained from a helium-neon-argon comparison lamp, and absolute fluxes were derived from observations of spectrophotometric standard stars. Small-scale fluctuations in the spatial response of the SIT were calibrated by observing flat fields, e.g., twilight sky, and the dome. The vidicon scan lines upon which the spectrum of the filaments on each side of the star were imaged were then co-added in order to arrive at the spectrum of each filament. The resulting spectra were then smoothed, and the final results are shown in Figure 2. Each scan represents the sum of six or seven scan lines, corresponding to a length of about 6" along the slit, which were centered on each of the two condensations along line AA (about 10" to the NE and to the SW of RR Pic). Since the spectra show no evidence for the C III–N III λ4640 emission feature which is quite prominent in the stellar spectrum of RR Pic (Wyckoff and Wehinger 1977), contamination of the spectra by scattered light from the central star must have been minimal.

Spectra are shown for both condensations in the blue region, but only the SW filament in the red. We were unable to complete the data reduction of the red scans of the gas to the NE of RR Pic before having to leave CTIO, although the raw data show the red spectra of the two filaments to be very similar. The blue spectra of the regions on either side of the star show no discernible differences, other than a slight contamination of the spectrum of the NE filament by the blue continuum from RR Pic, partly caused by S-distortion in the tube, which was not entirely corrected for at the short wavelength end of several scan lines.

The spectra of the filaments are very similar to that of a high-excitation planetary nebula such as NGC 2022 (Kaler 1976). The faintness of the filaments has caused the signal-to-noise ratio of the scans to be such that only the stronger lines appear above the noise, but the line identifications are fairly straightforward and are given in Figure 2. The most unusual feature is the line appearing at λ4227, initially thought by us to perhaps be due to Ca I λ4226. However, the presence of moderately strong Ca I emission is inconsistent with the level of ionization of the other lines, and with the absence of Ca II H and K emission. Therefore, we have seached for an alternative identification among lines seen at that wavelength in planetary nebulae or in other novae. In fact, a number of high-excitation planetaries have a line at this wavelength, due to [Fe V] λ4227. And, in the slow nova RR Tel, which like RR Pic displayed a rich spectrum due to iron near light maximum, there has been a strong [Fe V] λ4227 line reported (Thackeray 1977). Because of the unusual strength of Fe emission lines in RR Pic during the period of decline, we are confident that the line at λ4227, and also accompanying weaker features at λ4071 and λ4142, is [Fe V] emission.

There are indications of several weaker lines in the spectra of the filaments which are blended with stronger features. The profile of Hγ from both filaments is asymmetric, suggesting that a line is present in the red wing of Hγ, which could be [O III] λ4363. The relative flux of the line is very uncertain, but, if present with sufficient strength to affect the profile of the Balmer line, would signify that the emitting gas must be moderately hot ($T_e \gtrsim 2 \times 10^4$ K). Also, the line at λ5890 is primarily night-sky Na I D emission, which was incompletely subtracted out of the spectra, partly due to time variations in the S-distortion of the image tube. The apparent absorption features which accompany the night-sky emission in the D lines and [O I] λ5577 were produced by the sky subtraction process. However, the Na I feature has a slight excess of emission over absorption that may be due to the presence of He I λ5876 in the filaments.

III. ANALYSIS

The fact that the filaments surrounding RR Pic have spectra so similar to those of high-excitation planetary nebulae suggests that they are photoionized. This suggestion is supported by the *OAO* observations of Gallagher and Holm (1974), who found RR Pic to be very hot ($T_* > 35{,}000$ K), radiating most of its energy in the far-ultraviolet. RR Pic was the most luminous of the novae observed with the *OAO* satellite, and its UV colors were comparable to those of very early-type stars. However, because of the insensitivity of color indices to effective temperature on the Rayleigh-Jeans tail of the Planck curve, the actual UV-radiation temperature of RR Pic may well exceed the limit Gallagher and Holm were able to put on it. In addition, the presence of an accretion disk will tend to flatten the energy distribution as compared to that of a normal stellar atmosphere with the same amount of ionizing flux.

The ionizing radiation field of old novae is not known well; however, it is believed to consist of radiation from both the accretion disk and the degenerate nova remnant. Tylenda (1977) has computed the expected UV flux from old nova systems, including a specific model for RR Pic, basing his calculations on a standard model in which accretion occurs onto a degenerate dwarf in a close binary system. He finds that there should be three main contributors to the radiation field, each characterized by thermal radiation of a different temperature and

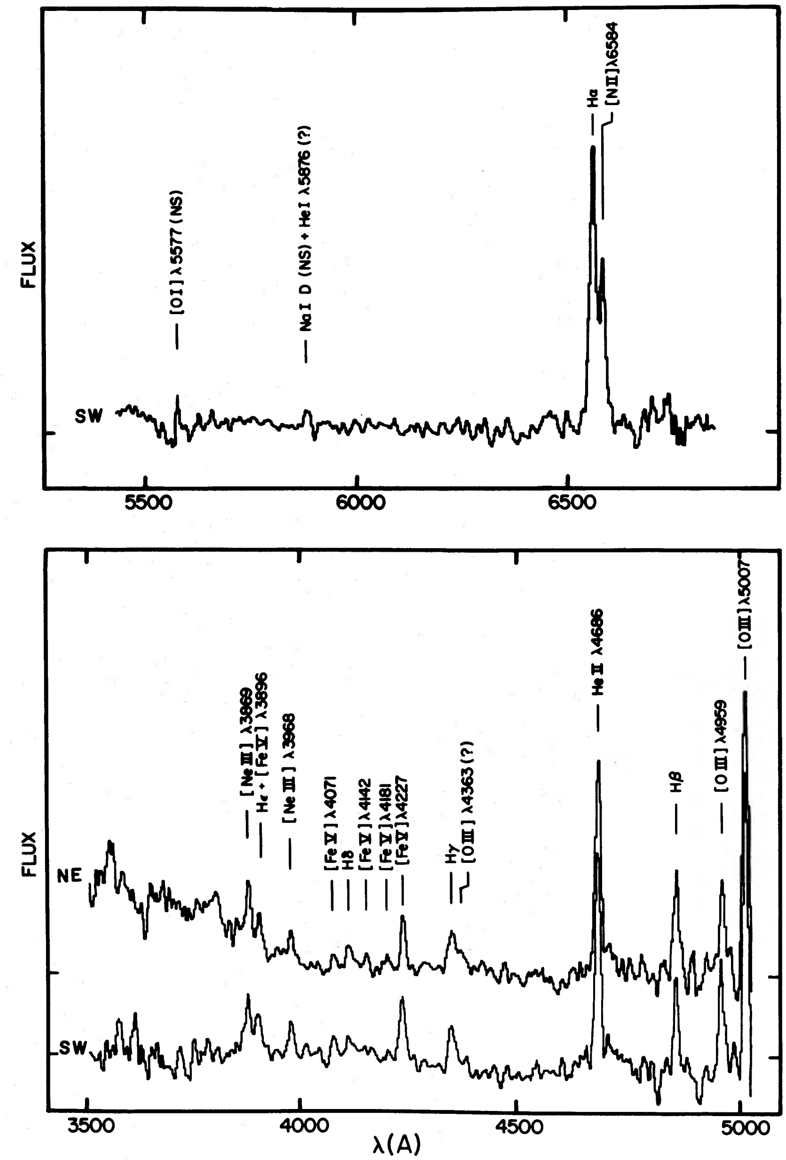

FIG. 2.—Spectral scans of the nebular condensations to the NE and SW of RR Pic. Line identifications are given, and the zero flux levels of the scans are denoted on the vertical axes.

luminosity. The sources of the radiation, and the parameters computed by Tylenda for RR Pic are: (*a*) the accretion disk ($T_d \sim 8 \times 10^4$ K, $L_d \sim 2.5 \times 10^{35}$ ergs s^{-1}); (*b*) a "hot spot," where matter streaming through the inner Lagrangian point collides with the accretion disk ($T_s \sim 3.6 \times 10^4$ K, $L_s \sim 7 \times 10^{33}$ ergs s^{-1}); and (*c*) a "boundary layer" on the surface of the white dwarf where the energy, i.e., angular momentum, of the accretion disk is liberated ($T_{bl} \sim 4.8 \times 10^5$ K, $L_{bl} \sim L_d$). For these parameters, only the boundary layer contributes to the ionizing continuum flux, and the effects of the other components on the ionization may be ignored.

We have attempted to account for the spectra of the RR Pic filaments in terms of a photoionization model, based on the type of radiation field suggested by Tylenda. Since the temperature and luminosity of the UV radiation field are at best only crudely determined from the theoretical calculations, we have considered a range of these parameters for the model in order to determine the values for which the predicted emission-line intensities agree best with the observations. The geometry we have used to represent the filamentary gas surrounding RR Pic is taken from Figure 1, which shows each of the condensations on opposite sides of RR Pic to be centered about 10″ away from the star and to have a radial thickness of about 4″. Taking the distance to the system to be 480 pc (McLaughlin 1960), the clouds extend from about 6×10^{16} to 9×10^{16} cm from RR Pic, neglecting possible projection effects.

1979ApJ...228..482W

TABLE 1
IONIZATION DISTRIBUTION FOR RR PIC FILAMENTS

Element	Ion I	II	III	IV	V	VI	VII	VIII
H	6×10^{-3}	0.99	...	...	...	...	...	...
He	2×10^{-4}	0.06	0.94	...	...	...	...	...
C	2×10^{-6}	1×10^{-3}	0.10	0.35	0.55	5×10^{-4}	3×10^{-7}	...
N	2×10^{-6}	8×10^{-4}	0.05	0.33	0.49	0.12	1×10^{-4}	...
O	1×10^{-6}	3×10^{-4}	0.03	0.37	0.45	0.14	5×10^{-3}	9×10^{-6}
Ne	4×10^{-8}	1×10^{-4}	0.01	0.24	0.58	0.16	3×10^{-3}	4×10^{-6}
Fe	3×10^{-5}	1×10^{-3}	3×10^{-3}	0.02	0.23	0.66	0.09	...

NOTE: Model parameters: T_{bl}(K): 2.5×10^5; L_{bl} (ergs s^{-1}): 4.4×10^{34}; N(cm^{-3}): 1.0×10^2; computed T_e(K): 1.6×10^4 (solar abundances).

The density of the gas is more difficult to establish, although its value is not crucial to the ionization calculations as long as the uncertain far-UV luminosity of the system can be adjusted within acceptable constraints to produce the observed level of ionization. The presence of [Fe v] λ4227 emission, which has a very low transition probability, $A_{21} = 1.1 \times 10^{-3}$ s^{-1} (Garstang 1957), and is therefore collisionally deexcited at densities $N_e \gtrsim 10^4$ cm^{-3}, sets an upper limit to the density. We have selected $N = 10^2$ cm^{-3} for the filaments, since roughly this density is required to produce the observed absolute Hβ flux from each condensation.

A number of ionization models of the RR Pic filaments were constructed under the assumption that the gas is photoionized by Planckian radiation of various temperatures and luminosities, and has solar abundances. Relative emission-line fluxes were computed for the models, and compared with the observed intensities. It was found that temperatures around $T_* \sim 4.8 \times 10^5$ K, as suggested by Tylenda, produced too high a level of ionization. The parameters which produced the best overall fits to the observed data are $T_* = 2.5 \times 10^5$ K and $L_* = 4.4 \times 10^{34}$ ergs s^{-1}, although nonsolar abundances seem to be required for certain elements. The basic characteristics of the model which best represents the level of ionization of the filaments are given in Table 1. The distribution of ionization through the condensations is fairly uniform because the knots are optically thin in the H and He ionizing continua, so the only change in the radiation field, hence ionization, is produced by the $1/r^2$ variation of the continuum flux through the clouds. The average fractional abundances of the ions of each element in the filaments are given in Table 1, and the computed electron temperature was $T_e = 16{,}500$ K. Table 2 lists the observed and computed line intensities relative to Hβ for this model, assuming the (logarithmic) relative abundances of H, He, C, N, O, Ne, and Fe to be essentially solar, i.e., 12.0, 11.0, 8.6, 8.3, 8.8, 8.0, and 7.4. The observed line fluxes have been corrected for interstellar reddening using the Whitford reddening curve and a value for the color excess of $E(B-V) = 0.07$ (McLaughlin 1960;

TABLE 2
EMISSION-LINE FLUXES FOR RR PIC FILAMENTS

Line	Relative Flux (Hβ = 100): Observed	Predicted: Solar Abundances*	Predicted: Modified Abundances*
[Ne v] λ3426	...	320	2400
[O II] λ3727	< 17	3	3
[Ne III] λ3869	67	7	67
Hε + [Fe v] λ3896	41	...	...
[Ne III] λ3968	26	2	22
[Fe v] λ4071	18	11	11
Hδ λ4101	29	26	26
[Fe v] λ4227	72	124	109
Hγ λ4340	56	47	47
He II λ4686	240	103	250
Hβ λ4861	100	100	100
[O III] λ4959	107	97	94
[O III] λ5007	256	291	283
Hα λ6563	280†	280	280
[N II] λ6584	97†	4	113

* See text.
† Fluxes normalized such that unreddened $F_{H\alpha} = 280$.

Gallagher and Holm 1974). The extinction for RR Pic ($b = -25°$) is uncertain; however, the photometric data indicate it to be small.

It is clear that some of the line strengths cannot be explained with solar abundances. In particular, the He, N, and Ne lines require enhancements. In spite of the fact that the helium is virtually all doubly ionized, the observed λ4686/Hβ flux ratio cannot be produced unless $N(\text{He})/N(\text{H}) \sim 0.2$. Since this result is insensitive to temperature (Osterbrock 1974), and the line strengths are fairly certain it seems definite that the helium abundance in the ejecta of RR Pic is enhanced by at least a factor of 2 over the Sun. The element abundances inferred from the other lines are less reliable because the ionization corrections for the heavier elements are less certain. According to the calculations, the intensity of [O III] λ5007 and the observed upper limit to [O II] λ3727, which is not present in the spectra, are consistent with the O/H ratio being solar. On the other hand, the computed [Ne III] λ3869 intensity is smaller than observed by a factor of about 10. This could conceivably be due to the computed fraction of Ne^{+2} being too small in the model. We have attempted to correct this problem by computing models with lower ionization in order to increase the [Ne III]/Hβ ratio to the observed level, but these models then have [O III]/Hβ ratios too high by an order of magnitude, in addition to giving unacceptable [O II]/[O III] ratios—a result which is independent of element abundances. For this reason, we believe the observed intensity of λ3869 requires a neon enhancement in RR Pic. Unfortunately, the UV transmission of the SIT was not good enough for us to try observing at wavelengths down to [Ne V] λ3426, which would provide more valuable information on the ionization level of the filaments.

The largest discrepancy between the observations and predictions occurs for [N II] λ6584. The fractional abundances of N^+ and O^+ in the condensations should be similar because of charge-exchange reactions with hydrogen, and with solar abundances the [O II] λ3727 line should have an intensity somewhat greater than [N II] λ6584, although this result is dependent somewhat upon the electron temperature, particularly if $T_e < 10^4$ K. However, the [N II] line is observed to be appreciably stronger than the [O II], which is not detected in our scans. Increasing the fractional abundance of N^+ by decreasing the level of ionization in the gas in order to correct the discrepancy would also have the effect of increasing the O^+ to an unacceptably high value, i.e., λ3727 would then be expected to be seen, in addition to producing too much [O III]. It should be noted that there is some uncertainty as to the correct [N II]/[O II] flux ratio, since the lines were not observed on the same scans. The absolute calibrations of the different scans are only of limited usefulness in this regard because red and blue scans were obtained on different nights, and different portions of the condensations may have been observed. The calibrations indicate an intensity ratio of $F_{\text{H}\alpha}/F_{\text{H}\beta} \sim 10$, which is considerably steeper than the radiative decrement, and inconsistent with the low reddening estimates. However, the relative intensities of Hβ/Hγ/Hδ on the blue scans are in fair agreement with the purely radiative decrement. Because of the uncertainty in the relative fluxes of the red to the blue scans, we have taken a conservative position and normalized the fluxes of the red scans to those of the blue by requiring the Hα/Hβ ratio to be the radiative value ($F_{\text{H}\alpha}/F_{\text{H}\beta} = 2.8$). This assumption leads to a ratio of [N II] λ6584/[O II] λ3727 $\gtrsim 6$. According to our calculations, this value of the relative line strengths could occur only if the N/O abundance is ~25 times solar. In spite of the uncertainties associated with this result, we believe the evidence is strong for a nitrogen enhancement with respect to oxygen and hydrogen in the RR Pic ejecta by at least an order of magnitude.

The iron abundance is difficult to determine with any accuracy from the flux of the [Fe V] emission because the cross sections for excitation of the upper levels of the transitions have not been calculated, and the photoionization and recombination cross sections for Fe are not known. Therefore, we have calculated the ionization of Fe by assuming the cross sections of the ions of Fe to be the same as the ions of Si which have similar ionization potentials. The resulting ionization distribution for iron is given in Table 1 with the other elements, but must be considered to be only approximate.

In order to compute the [Fe V] line intensities expected from our RR Pic model, we have used the conservation rules discussed by Osterbrock (1963) to obtain an approximate value of $\Omega(3d^4\,{}^5D\text{–}{}^3H) = 12$ for excitation of the upper term of λ4227. Collision strengths from ${}^5D$ to other terms of Fe V have been semiempirically determined by Shields (1978) from observations of the [Fe V] lines in planetary nebulae, and we have used the value $\Omega({}^5D\text{–}{}^3P_1) = 1.1$ he derived for excitation of λ4071. Our assumed value of $\Omega({}^5D\text{–}{}^3H)$ is very similar to the values found by Shields for excitation of other triplet levels from the ${}^5D$ ground state. Using these cross sections, the [Fe V] fluxes we compute from the model of the filaments are $F(\lambda4227)/F(\text{H}\beta) = 1.2$ and $F(\lambda4071)/F(H\beta) = 0.1$, as compared with the observed values of 0.7 and 0.2, respectively. Within the uncertainties in the predicted fluxes caused by the approximate ionization and excitation cross sections, the results must be considered to be consistent with a solar Fe/H abundance in RR Pic. The appearance of [Fe V] lines at intensities substantially greater, relative to other lines, than seen in planetary nebulae would seem to indicate that the gas-phase abundance of iron is much higher in the nova shell than in planetaries. In fact, this is the case inasmuch as Shields's analysis has demonstrated that planetary nebulae are generally very depleted in gaseous Fe/H, compared with solar values.

Iron lines frequently appear during the nebular stages of novae. The unusual strength of the Fe emission in RR Pic, compared to its intensity in other novae such as V1500 Cyg, is probably due to the greater enhancements of CNO in other objects, which cause the Fe/CNO ratio to be larger in RR Pic than in most novae. For example, the CNO abundances derived for the ejecta of V1500 Cyg (Ferland and Shields 1978) and DQ Her (Williams *et al.* 1978) show the CNO/H abundance ratio to be substantially higher than we have found in the RR Pic filaments. Consequently, Fe emission lines do not have strengths comparable to the CNO lines in most novae.

No carbon lines were observed in the RR Pic filaments, and thus little information can be deduced about its abundance. We included carbon in the calculations because of its possible effect on the cooling, but the high level of ionization causes the contribution of C to the cooling to be small compared to that produced by the observed N, O, and Ne forbidden lines, even if its abundance is considerably enhanced. Since C III and C IV recombination lines would not be expected to be seen in our scans unless the C/H ratio exceeds the solar value by a factor of about 200, all that can be concluded is that this number represents a rough upper limit to the C/H ratio in the filaments.

It is difficult to make a quantitative assessment of the uncertainties in the abundances we have deduced for RR Pic. Substantially different results could be obtained, depending on the assumptions made about important parameters such as the stellar radiation field, gas density, etc., which cannot be uniquely determined from our observations. For example, if small high-density condensations occur in the filaments and the [N II] emission is produced in them, the large [N II]/[O II] intensity ratio could conceivably be explained by the collisional de-excitation of λ3727 without requiring a large N/O abundance. Densities required for this to occur would be very high, $N_e \gtrsim 10^5$ cm^{-3}, for which there is no direct evidence. Second, the Ne enhancement required by our model would be unnecessary if the ionization of the model were unrealistically high, producing too little Ne^{+2} (and O^{+2}). However, lower ionization would lead to a large increase in the predicted λ5007 flux, which would then require the derived O/H abundance in RR Pic to be much less than solar.

An important point should be made regarding our projections of the abundances of RR Pic based on the model calculations. It is not self-consistent to construct a model with solar abundances, as we have done, and then attribute all discrepancies between theoretical predictions and observed line intensities solely to differences in the assumed abundances. Changing the heavy element abundances in a plasma also changes the cooling rate, hence the electron temperature (which affects the line emissivities), and so this problem must be solved iteratively. For example, increasing the abundances of N and Ne, as we have suggested, may drive down T_e, requiring greater abundances for *all* the heavy elements in order to produce the observed line fluxes. Therefore, we have constructed another model identical to the solar abundances model we have previously described, with the exception that the element abundances were taken to be those suggested by that model, i.e., log (10^{12} X/H) = 12.00, 11.36, 8.60, 9.70, 8.78, 9.00, and 7.40, for H, He, C, N, O, Ne, and Fe, respectively. The ionization distribution of this model is virtually identical to that given in Table 1 for the model with solar abundances, but the computed electron temperature is slightly lower, T_e = 15,000 K, because of the increased cooling from the heavy-element enhancements. The computed line fluxes for the model are given in the last column of Table 2, and they show general agreement with the observed line strengths. This is, of course, no guarantee that this model is unique, particularly since one can always arbitrarily adjust abundances for elements for which only one line is observed, in order to force agreement between the computed and observed intensities. In spite of the uncertainties, however, we believe this model gives a basic representation of conditions within the gas surrounding RR Pic.

IV. SUMMARY

Observations of the filaments surrounding RR Pic show them to have emission spectra which are similar to those of high-excitation planetary nebulae. This similarity, and the fact that RR Pic is known from *OAO* photometry to emit mostly in the ultraviolet, suggests that the gas around RR Pic is photoionized. A photoionization model of the filaments, based upon calculations by Tylenda of the radiation field, satisfactorily accounts for the spectrum. The strong He II λ4686 line requires the He/H ratio to be more than twice the solar value, even though all of the He is doubly ionized. The [O II] λ3727 line is not seen because the ionization of the condensations is quite high. The fact that the low-ionization line [N II] λ6584 is seen with moderate strength requires the N/O abundance to be much higher than normal. On the other hand, the relatively strong [Fe V] λ4227 line does not indicate an enhancement of Fe/H, considering the level of ionization in RR Pic. Rather, the weakness of [Fe V] lines in planetary nebulae is indicative of gaseous-iron depletion in these objects. Unfortunately, the spectral coverage of the instrument configuration used to obtain our data did not extend from [Ne V] λ3426 to [O III] λ5007. In order to obtain the latter line, we had to bypass the [Ne V] line. Future observations of [Ne V] in RR Pic would serve as a test of our photoionization model, since we predict the line to be quite strong.

Overabundances of helium may not be uncommon in novae. From a heterogeneous set of He abundance determinations for a number of objects, Collin-Souffrin (1977) found a mean value of He/H = 0.25, by number. However, her suggested correlation of increasing He content in faster novae is not supported by our high He abundance for a slow nova, or by Ferland's (1978) finding of normal He in the very fast nova V1500 Cyg. The abundance analyses summarized by Collin-Souffrin are also consistent with N enhancements in novae, although the ratio of N/O is usually only slightly above solar. The large value of N/O in RR Pic is therefore unusual, but could possibly be accounted for if equilibrium CNO burning has occurred and converted most of the C and O into N. This is predicted to occur in slow novae by the thermonuclear runaway model of Sparks, Starrfield, and

Truran (1978), who estimate that N/O in the ejecta should be ~ 50 times solar.

It is worth noting the differences between the shells of the two slow novae (DQ Her and RR Pic) that have now been observed spectroscopically. The shell around DQ Her is moderately ionized, but very cold (Williams *et al.* 1978). Apparently, UV radiation from the nova remnant has diminished and is now too weak to sustain ionization, and the gas has cooled to ~ 400 K and is in the process of recombining. Recombination lines of C, N, and O are observed with strengths which require these elements to be enhanced over their solar abundances by factors of 100. By contrast, the filaments around RR Pic are almost certainly photoionized, and the gas is highly ionized and hot ($T_e \sim$ 15,000 K). Analysis of line intensities indicates that the abundances of He, N, and Ne are enhanced, but the O and Fe abundances are not, although these results are not as definite as those for DQ Her.

The obvious questions that arise from this comparison are (*a*) why are the ultraviolet continua of the DQ Her and RR Pic systems so different? and (*b*) if the heavy-element enhancements are real, why were RR Pic and DQ Her both slow novae rather than fast novae, as the calculations of Sparks, Starrfield, and Truran (1978) seem to imply they should have been? In order to answer the latter question, alternative theories to the standard CNO thermonuclear runaway model as the only cause of the nova outburst may need to be explored. In addition, it is anticipated that spectroscopic investigations of the ejecta surrounding fast novae will help to resolve these questions.

We should like to acknowledge the assistance of CTIO staff members whose help was indispensable to this investigation: John Graham kindly obtained the photograph of the RR Pic shell, Pat Osmer was invaluable in helping with the SIT data reduction, and Barry Lasker helped us work out some instrumental problems at the telescope. This research has been supported by the National Science Foundation through grant AST 77-15865 to the University of Arizona.

REFERENCES

Collin-Souffrin, S. 1977, in *Novae and Related Stars*, ed. M. Friedjung (Dordrecht: Reidel), p. 123.
Ferland, G. J. 1978, *Ap. J.*, **219**, 589.
Ferland, G. J., and Shields, G. A. 1978, *Ap. J.*, **226**, 172.
Gallagher, J. S., and Holm, A. V. 1974, *Ap. J.* (*Letters*). **189**, L123.
Garstang, R. H. 1957, *M.N.R.A.S.*, **117**, 393.
Jones, H. S. 1931, *Ann. Cape Obs.*, Vol. **10**, Pt. 9.
Kaler, J. B. 1976, *Ap. J. Suppl.*, **31**, 517.
McLaughlin, D. B. 1936, *A.J.*, **45**, 145.
———. 1960, in *Stellar Atmospheres*, ed. J. L. Greenstein (Chicago: University of Chicago Press), p. 585.
Osmer, P. S., and Smith, M. G. 1976, *Ap. J.*, **210**, 267.
———. 1977, *Ap. J.*, **213**, 607.
Osterbrock, D. E. 1963, *Planet. Space Sci.*, **11**, 621.
Osterbrock, D. E. 1974, *Astrophysics of Gaseous Nebulae* (San Francisco: Freeman).
Payne-Gaposchkin, C. 1957, *The Galactic Novae* (Amsterdam: North-Holland).
Shields, G. A. 1978, *Ap. J.*, **219**, 559.
Sparks, W. M., Starrfield, S. G., and Truran, J. W. 1978, *Ap. J.*, **220**, 1063.
Thackeray, A. D. 1977, *Mem.R.A.S.*, **83**, 1.
Tylenda, R. 1977, *Acta Astr.*, **27**, 235.
Williams, R. E., Woolf, N. J., Hege, E. K., Moore, R. L., and Kopriva, D. A. 1978, *Ap. J.*, **224**, 171.
Wyckoff, S., and Wehinger, P. A. 1977, *IAU Colloq. No. 42, The Interaction of Variable Stars with Their Environment*, ed. R. Kippenhahn, J. Rahe, and W. Strohmeier (Bamberg: Remeis-Sternwarte), p. 201.

J. S. GALLAGHER: Department of Astronomy, University of Illinois, Urbana, IL 61801

R. E. WILLIAMS: Steward Observatory, University of Arizona, Tucson, AZ 85721