THE ASTROPHYSICAL JOURNAL, 219:589–594, 1978 January 15

THE HELIUM ABUNDANCE OF EJECTA FROM V1500 CYGNI (NOVA CYGNI 1975)

G. J. FERLAND
McDonald Observatory and Department of Astronomy, University of Texas, Austin
Received 1977 May 27; accepted 1977 July 20

ABSTRACT

We have studied the He emission spectrum of V1500 Cygni (Nova Cygni 1975) in the nebular phase of the outburst. The steep Balmer decrement is interpreted as evidence for optical depth in the Balmer series. The observed strength of Hβ was corrected for self-absorption by matching observed and predicted Balmer decrements. He I recombination lines yield the He$^+$ abundance. The good agreement between the abundances obtained from triplet (λ5876) and singlet (λ6678) lines shows that these lines are unaffected by optical-depth and collisional excitation effects. The He^{++} abundance was derived from the He II line λ5412. Our principal result is that the He abundance is identical to that found in planetary nebulae, He/H = 0.11 $\pm$ 0.01. The He$^+$/H ratio decreases and the He^{++}/H ratio increases in the interval, but the total abundance He/H is constant to within the errors. This constitutes a check on the analysis.

We derive the color temperature of the ionizing radiation field by matching the observed ratio He^{++}/He$^+$, with the models of Hummer and Mihalas. The color temperature increased from below 5×10^4 K on day 10 to about 1.7×10^5 K by day 300. High temperatures during the late decline are supported by the presence of strong lines of [Ne V] and [Fe VII].

Subject headings: stars: abundances — stars: individual — stars: novae

I. INTRODUCTION

The helium content of nova ejecta is a valuable clue to the evolutionary state of the stars involved. Novae are generally believed to occur in binary systems where the late-type component is transferring mass onto an accretion disk surrounding a white dwarf. Starrfield, Sparks, and Truran (1974) have shown that many features of the nova outburst (e.g., ejected mass, expansion velocities, peak luminosities) can be reproduced, if the material in the hydrogen-rich envelope of the exploding white dwarf has a CNO abundance enhanced by 10–100 relative to hydrogen. Colvin *et al.* (1977) have suggested that this enhancement could be the result of convective mixing of the envelope with the carbon-rich core of the white dwarf. Furthermore, the material ejected in the outburst may have been transferred from the late component and so affected by the evolution of the primary. Both of these processes (convective mixing and double mass transfer) might affect the He/H ratio in the ejecta.

In this paper we derive the He abundance of the ejecta from the very fast galactic nova V1500 Cyg using data obtained during the nebular phase. The visual light curve has been discussed by Young *et al.* (1976). The nova had a very large outburst range ($\delta m \gtrsim 20$ mag) and the fastest rate of descent of the novae of this century. Spectroscopically, it was very similar to the very fast novae CP Pup and CP Lac (Tomkin, Woodman, and Lambert 1976; Ferland 1977*a*).

At the McDonald Observatory an extensive series of spectrophotometric observations began shortly (1975 August 30.3) after discovery. The data of the first 20 days have been discussed by Tomkin *et al.*, and another discussion is in preparation (G. J. Ferland, D. Lambert, and J. Woodman). The data have been reduced to absolute fluxes (Ferland 1977*b*). A color excess, $E(B-V)$, of 0.50 $\pm$ 0.05 mag was assumed.

We shall derive the He abundance from data obtained during the late phases of the outburst, the so-called nebular phase. At that time, the nova spectrum shows a rich display of recombination, collisionally excited, and fluorescent emission lines. We select ratios of H and He recombination lines, which have only a slight temperature and density dependence if the lines are not subject to self-absorption. We derive a cosmic He/H ratio (0.11 $\pm$ 0.01) after correcting Hβ for optical-depth effects. Finally, we use the ionization ratio He^{++}/He$^+$ to derive the color temperature of the ionizing radiation field.

II. THE METHOD

During the nebular stage, the shell is similar to a planetary nebula or H II region but has very large expansion velocities ($v \approx 10^3$ km s^{-1}). The He/H ratio can be determined quite accurately, since these emission lines are formed by recombination and the cross sections have nearly the same temperature dependence. If the lines are optically thin, then

$$j(\text{line}) = \alpha_{\text{line}}(T)N(\text{atom})N_e h\nu \ ;$$

so the abundance ratio becomes

$$\frac{N(\mathrm{He})}{N(\mathrm{H})} = \frac{j(\mathrm{He\,I})}{\alpha_{\mathrm{He\,I}}(T)} \frac{\alpha_{\mathrm{H}\beta}(T)\nu_{\mathrm{H}\beta}}{j(\mathrm{H}\beta)\nu_{\mathrm{He\,I}}} + \frac{j(\mathrm{He\,II})}{\alpha_{\mathrm{He\,II}}(T)} \frac{\alpha_{\mathrm{H}\beta}(T)\nu_{\mathrm{H}\beta}}{j(\mathrm{H}\beta)\nu_{\mathrm{He\,I}}} ,$$

where j is the flux in an emission line and $\alpha(T)$ is the effective recombination coefficient (Osterbrock 1974). The ratios are not temperature-sensitive, since the effective recombination coefficients have a similar temperature dependence [$\alpha(\lambda 5876\ \mathrm{He\,I})/\alpha(\mathrm{H}\beta) \propto T^{0.15}$, Peimbert 1975]. A typical set of data is illustrated in Figure 1.

III. THE BALMER-LINE STRENGTHS

We begin with a discussion of the optical depth in the Balmer series and its effect on the observed strength of Hβ. In Figure 2 we show the ratio $j(\mathrm{H}\alpha)/j(\mathrm{H}\beta)$, a measure of the Balmer decrement. The last three observations of Hα are strongly affected by [N II] λλ6548, 6584. We have removed this contamination in the last observation (for which two points are plotted) by obtaining a high-resolution scan of the [N II]–Hα complex. The [N II] contribution to the blend was estimated by assuming that the λ6548 profile was identical to that of [O III] λ5007 and by subtracting an amount predicted from the outer wings of the complex, which are affected only by [N II].

We attribute the variable Balmer decrement to self-absorption in the Balmer series. Ferland (1977*d*) has studied the Balmer decrement, the strength of the O I λ8446 fluorescence, and the time-dependent line asymmetry (the so-called V/R ratio) and found that all three are strongly correlated. This may be due to an extensive partially ionized zone in the ejected material (Strittmatter *et al.* 1977). Lα trapping builds up a significant population in the first excited state of hydrogen. Repeated scattering of Hα results in an ambient population of Lβ photons which then produces λ8446 through the wavelength coincidence first noted by Bowen (1947) and later studied by Shields (1974) and Netzer and Penston (1976). Multiple scattering of Hβ results in its eventual conversion into Hα plus Pα, which produces a steep Balmer decrement. Finally, optical depth in the outward direction

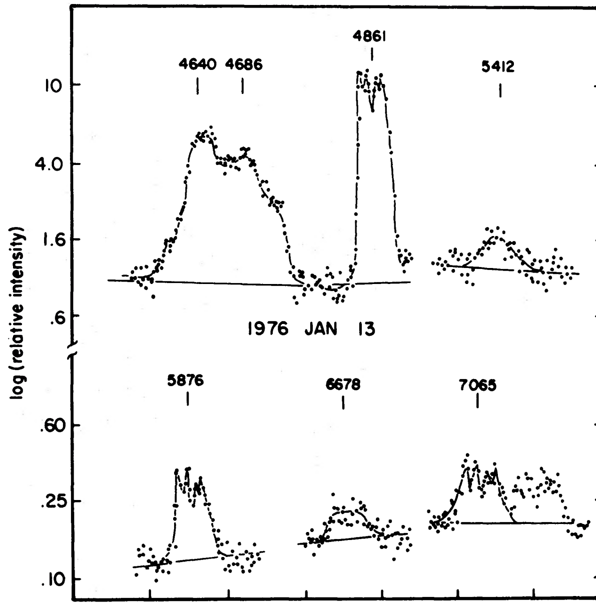

FIG. 1.—He and H lines of Nova Cygni 1975, on 1976 January 13. These observations were obtained by J. Woodman with the coudé scanner of the 2.7 m reflector. See Tomkin *et al.* for more details about the observational procedure. The y-axis is logarithmic.

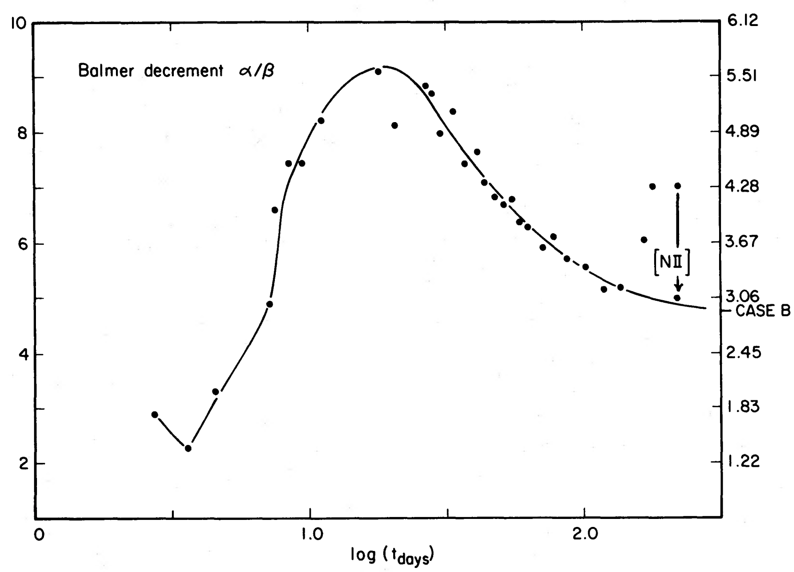

FIG. 2.—Balmer decrement. Observed values of the ratio Hα/Hβ are indicated at left. The de-reddened [$E(B - V) = 0.50$] values are indicated at the right, with the case B ratio indicated. The last three observations are affected by [N II] contamination, which has been estimated and removed from the last observation. The envelope approached case B conditions as it evolved.

results in backscattering and a small V/R ratio. This behavior is a common feature of the nova outburst, as is shown by the data presented in Payne-Gaposchkin (1957).

Malakpur (1973) attributed the variable Balmer decrement of HR Del to the formation and dissipation of circumstellar dust. This cannot apply to Nova Cygni 1975, since the free-free energy distribution did not change during the time we consider (Gallagher and Ney 1976).

Since Netzer (1975, see his Fig. 3) has considered the effects of self-absorption on both the Balmer decrement and the effective recombination coefficient, we can correct the observed strength of Hβ to that expected for classical case B conditions. The correction is never large (less than or equal to 0.2 dex). The latter observations (Fig. 2) have shown the envelope to be nearly in case B conditions: These scans do not require any correction.

IV. THE He^+ ABUNDANCE

In this section we begin by showing that it is unlikely that there is an outer H II, He I zone after day 15 (we reckon time after outburst from t_0 = 1975 August 28.5, following Ennis *et al.* 1977). We then consider which lines are most likely to give reliable results and derive the He^+/H ratio.

The ionization structure of photoionized nebulae has been studied by many authors; a complete discussion of the He structure is given in Hummer and Seaton (1964) and in Harmon and Seaton (1966). For radiation fields with color temperatures greater than 6×10^4 K, there will be an inner H II, He III zone where the ionizing photons with energies greater than 4 rydbergs are absorbed. Beyond this is a He II, H II zone where the remainder of the radiation is attenuated. For radiation fields with color temperatures below $T_{\rm crit} \approx 5 \times 10^4$ K, the photons with energies greater than 1.8 rydbergs will be depleted before those between 1.8 and 1.0 rydbergs. In this case there will be an outer He I, H II zone, and we shall underestimate the He abundance. If the color temperature is greater than $T_{\rm crit}$, the outer edges of the He II, H II zones will be nearly coincident, and the correct He/H abundance will be obtained.

We will show later that He II is present in the nova spectrum after day 15. This implies a central object with a color temperature $T_c \gg 6 \times 10^4$ K, and a negligibly small outer H II, He I zone (Harmon and Seaton 1966) to the nebula.

A Grotrian diagram of the He I atom is reproduced as Figure 3. The He singlets are very likely to be optically thin (the He I $2 \rightarrow 1$ transition, λ584, can photoionize hydrogen; so λ584 trapping is unlikely to create a significant population in $2\,^1P$). Unfortunately, the singlets are weak, because only about one-fourth of the recombinations are to singlet states. The triplets have much greater strength, but the metastability of the $2\,^3S$ state may cause large optical depths in $2\,^3S$–$n\,^3P$ transitions. Furthermore, their strength may be enhanced by collisional excitation from $2\,^3S$ (MacAlpine 1976).

We proceed by considering the strongest available singlet line, λ6678 (λ5015 is hopelessly blended with [O III] λ5007), and a triplet line arising from $2\,^3P$, λ5876, which is free of the Na D lines during the nebular phase. The ratio of λ6678 to Hβ is shown in Figure 4, both before and after correction of Hβ for self-absorption. The ratio as plotted has not been corrected for interstellar reddening. We summarize our results in Table 1, where we have divided the data into six groups which consist of four, five, five, five, five, and two scans, respectively. An entry for

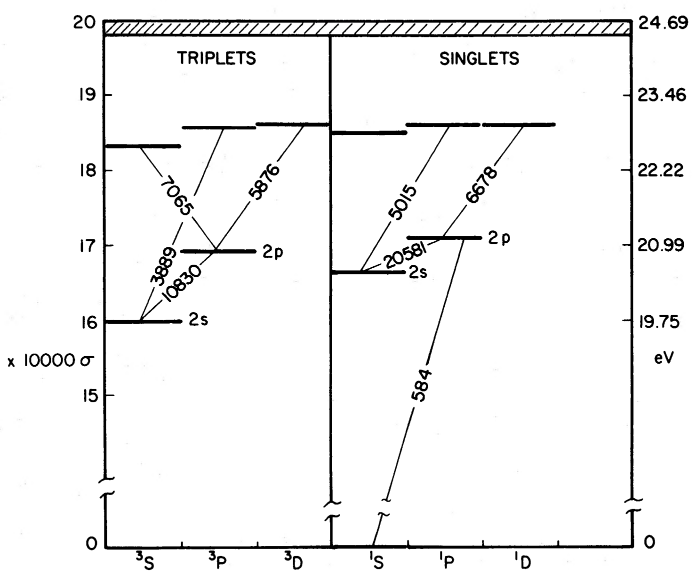

FIG. 3.—Grotrian diagram of He I showing the lines considered in this study. Excitation potentials in 10^4 wavenumbers and in electron volts are indicated on the left and right, respectively.

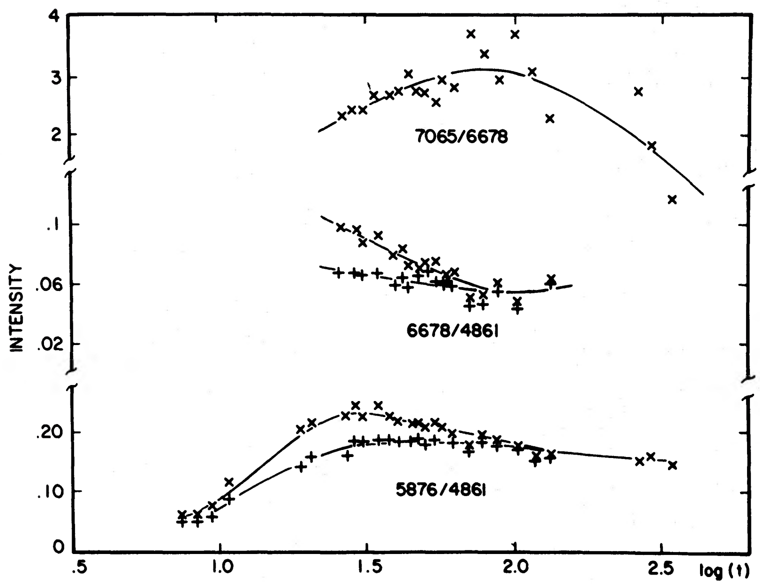

FIG. 4.—Relative line strengths versus time. (*a*) The ratio 7065 ($3\,^3S$–$2\,^3P$)/6678 ($3\,^1D$–$2\,^1P$). The former is enhanced by degradation of λ3889, while the latter should not be affected by optical depth. (*b*) The ratio 6678/Hβ. The upper curve (+) is the ratio before correction of Hβ for optical depth, while the lower curve (×) represents the corrected ratio. (*c*) The ratio 5876/Hβ, presented in the same manner as (*b*). None of these ratios has been corrected for interstellar reddening.

λ6678 is absent in the first group, because the line was overwhelmed by the red wing of Hα until day 15.

We now consider the λ5876/Hβ ratio. Three-quarters of all He I recombinations are to the triplets, all of which eventually result in population of the $2\,^3S$ state. As shown in Figure 5, λ10830 is one of the stronger lines of the nova spectrum. The population of $2\,^3S$ produces large optical depths in $2\,^3S$–$n\,^3P$ lines, such as λ3889 ($2\,^3S$–$3\,^3P$). This results in repeated scattering of the photon, with a 10% probability of decay into λ7065 via $3\,^3P$–$3\,^3S$–$2\,^3P$. The inverse conversion is quite unlikely. This process produces on abnormally strong λ7065, as we see in Figure 4; λ7065 may be even further enhanced by He I absorption of H I λ3889 (Pottasch 1962).

The λ5876 line arises from the $2\,^3P$ state. A buildup of the $2\,^3P$ population may result from λ10830 trapping; but conversion of λ5876 into λ3889 is unlikely, since the branching ratio out of $3\,^3D$ (1.8×10^{-4}, Wiese, Smith, and Glennon 1966) strongly favors scattering of λ5876. Collisional coupling of the L states of level 3 would affect the strength of λ5876 for high electron densities. Robbins (1968) found that the effective recombination coefficient for λ5876 changed by only 4% when the electron density changed from 10^3 to 3×10^7 cm^{-3}, so we can safely neglect collisional coupling. MacAlpine (1976) has discussed collisional excitation of λ5876 from $2\,^3S$ and found that it is an important excitation mechanism for densities greater than 10^9 cm^{-3}. The low electron densities present in the nebular stage ($N_e \approx 10^7$ cm^{-3}) suggest that this effect may be ignored.

In Figure 4 we show the observed ratio $j(5876)/j(4861)$, both before and after correction of Hβ for self-absorption. In Table 1 we list the mean ratios for our six groups of data. In column (5) of Table 1 we list the He^+/H abundances obtained from the dereddened flux ratios, an electron temperature of 1.5×10^4 K, and the tables of Osterbrock (1974). This result is a straight mean of the abundances obtained from λλ6678, 5876. The error, estimated from the difference between the two independent results, is about 5%.

TABLE 1

SYNOPSIS OF RESULTS

Time (days) (1)	5876/4861 (2)	6678/4861 (3)	5412/4861 (4)	He^+/H (5)	He^{++}/H (6)	He/H (7)	T_{color} (8)
7–11.......	0.06 ± 0.02	...	0.0	0.03	0.0	0.03	$< 5 \times 10^4$ K
18–30......	0.170 ± 0.01	0.071 ± 0.005	0.005 ± 0.002	0.097 ± 0.01	0.005 ± 0.001	0.102 ± 0.01	1×10^5 K
31–50......	0.176 ± 0.005	0.062 ± 0.004	0.013 ± 0.003	0.093 ± 0.001	0.012 ± 0.003	0.105 ± 0.004	1.2×10^5 K
51–75......	0.172 ± 0.008	0.058 ± 0.007	0.018 ± 0.003	0.090 ± 0.004	0.016 ± 0.002	0.106 ± 0.005	1.2×10^5 K
75–140.....	0.160 ± 0.01	0.051 ± 0.007	0.028 ± 0.008	0.080 ± 0.008	0.026 ± 0.007	0.106 ± 0.01	1.3×10^5 K
267–360....	0.155 ± 0.02	...	0.058 ± 0.015	0.075 ± 0.01	0.053 ± 0.02	0.128 ± 0.025	1.7×10^5 K

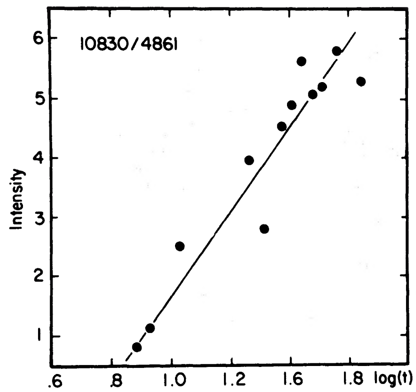

FIG. 5.—The 10830 line relative to Hβ. Reddened, uncorrected ratios are plotted. Data are not available after day 70, because the nova became too faint for S-1 observations with our single-channel scanner. The behavior is similar to that of 7065/6678.

V. THE He^{++} ABUNDANCE

In the preceding section, we have derived the abundance of He^{+} in the nova ejecta. We must now obtain that of He^{++} to complete our analysis. The strongest He II line, the Pα λ4686, unfortunately lies within the broad blend of lines dominated by N III λ4640 (Fig. 2). We can obtain an upper limit to the power in λ4686 by integrating over the region where it would be expected to lie (assuming that its profile is identical to that of Hβ). We obtain $j(4686)/j(4861) \leqslant 0.4$, where the equality holds if no other lines contribute to this part of the blend. This corresponds to a He^{++} abundance of $He^{++}/H \leqslant 0.04$, which shows that He^{++} cannot make a large contribution to the He abundance.

The He II Pβ line (λ3203) is present on our scans; but unfortunately, the color calibration of our spectrometer is quite poor ($\sim$30%) in this region because of the combined effects of the narrow entrance slit and atmospheric dispersion. However, the observed mean ratio, $j(3203)/j(4861) \approx 0.08 \pm 0.03$, yields a consistent He^{++} abundance (0.02 ± 0.01).

The strongest Pickering series line present in our data is $7 \rightarrow 4$, λ5412, shown in Figure 2. In Figure 6 we show the temporal development of the ratio $j(5412)/j(4861)$, both before and after correction of Hβ for self-absorption. Again, reddened values are plotted. The increase of the strength of the He II lines relative to the Balmer series or He I lines is a common property of declining novae (Gallagher and Starrfield 1976); McLaughlin (1949) found that λ4686 increased relative to He I throughout the decline of GK Per. We will show below that this may be an indication that the color temperature of the ionizing radiation field increased as the nova grew fainter.

The mean $j(5412)/j(4861)$ ratio for each group of data is listed in Table 1, together with the He^{++}/H abundances. In column (7) of Table 1 we list the total He/H ratio for the ejected material. The last group of data is quite noisy; it consists of two scans which were obtained when the object was very faint ($y \approx 13$ mag).

The only discrepant abundance is that obtained between days 7 and 11, He/H = 0.03. This suggests that the central object had a color temperature of less than $T_{\rm crit} \approx 5 \times 10^4$ K during this period and that an extensive outer He I, H II zone was present in the shell at that time. The presence of such a zone is also suggested by the absence of He II recombination lines, which suggests a low color temperature, $T_{\rm color} < 6 \times 10^4$ K.

That no significant trend in the He/H abundance is present after day 18 demonstrates that our analysis is internally consistent. The mean of the last five groups of data is He/H = 0.109 ± 0.01.

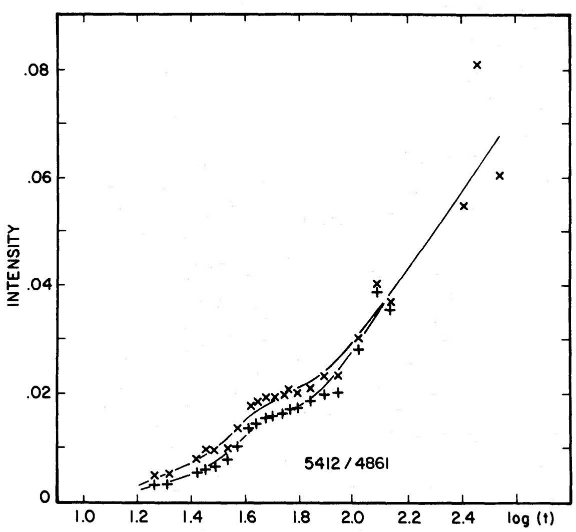

FIG. 6.—He II 5412/Hβ. These ratios are plotted as in Fig. 4.

VI. THE COLOR TEMPERATURE

If the shell is radiation-bound, then the ionization ratio He^{++}/He^{+} is a sensitive indicator of the color temperature of the radiation field. The presence of He I lines indicates that the shell is radiation-bound to photons with energies greater than 4 rydbergs, while [O I] emission throughout the decline (Ferland, Lambert, and Woodman 1977) suggests that the shell was radiation-bound to photons with energies greater than 1 rydberg. Under these conditions and with the assumption of steady state, the number of recombinations is equal to the number of photoionizations, which in turn is equal to the number of photons within the pertinent energy range intercepted by the ejecta. Thus

$$\frac{N(\mathrm{He}^{++})}{N(\mathrm{He}^{+})} = \left(\int_{4\nu_0}^{\infty} \frac{F_\nu}{h\nu}\, d\nu\right) \Big/ \left(\int_{1.8\nu_0}^{4\nu_0} \frac{F_\nu}{h\nu}\, d\nu\right) .$$

The temperature trend is clear; the central object grew hotter as it declined. We can make quantitative estimates of the color temperature by comparing our ionization ratios with the planetary nebula nuclei models of Hummer and Mihalas (1970). Although these models may not be valid for a nova remnant, which is certainly not in hydrostatic equilibrium or steady state, they are probably a better approximation of the emergent flux than a blackbody. In column (8) of Table 1, we list the temperatures corresponding to these ionization ratios. We see that the temperature of the central object increased from below 5×10^4 K on day 10, to 1.7×10^5 K by day 300. This is in agreement with other observations that the ionization of the shell is increasing—for instance, the increasing prominence of [Ne V] and [Fe VII] lines in the spectrum (Ferland, Tomkin, and Woodman 1976). This behavior is a characteristic shared with most galactic novae (Payne-Gaposchkin 1957).

VII. DISCUSSION

Our principal result has been that the He/H ratio of the ejecta from V1500 Cyg (0.11 ± 0.01) is cosmic. It is identical to the mean derived by Osterbrock (1974) from observations of planetary nebulae. It appears that the majority of the material ejected by Nova Cygni 1975 has not undergone any processing which has affected the helium abundance.

The He/H ratio for other novae is ill-determined. Pottasch (1959) studied four novae to obtain He/H $\approx$ 0.15 with a large scatter (the results for separate objects ranged from 0.06 to 0.32). Later Pottasch (1967) studied the recurrent nova RS Oph and found He/H = 0.45, a value similar to that of the Crab Nebula (Davidson and Tucker 1970). Collin-Souffrin (1976) has reviewed determinations of abundances in nova ejecta. She found that the mean He/H ratio was 0.25 and noted that the enhancement of both He and the metals tended to decrease with time. We would have derived essentially the same result, if we had neglected the effects of optical depth in the Balmer series. In particular, we would have derived a He/H ratio of 0.18 during the early decline, decreasing to 0.11 by day 100. It is important to bear in mind that V1500 Cyg was an extremely fast nova; other novae would have required much longer than 100 days to reach case B Balmer-emission conditions. Nova Cygni 1975 had declined by 8 mag in *V* by day 100 (Williamon 1977). Table 4 of McLaughlin (1960) shows that a typical fast nova such as GK Per or V603 Aql required about 300 days to decline 7 mag; DQ Her, a slow nova, required 1000 days. Many investigations may have been performed before the Balmer series self-absorption became negligible.

The possibility that all novae do not have the same helium content remains, however. Spectrophotometric observations of old nova ejecta, which are likely to be optically thin to line radiation, are desperately required if we are to decide whether other novae have cosmic or enhanced helium abundances.

I am extremely grateful to David Lambert for his careful review of the manuscript, and to J. Tomkin, R. Robbins, and G. Shields for their helpful comments.

REFERENCES

Bowen, I. 1947, *Pub. A.S.P.*, **59**, 196.
Collin-Souffrin, S. 1976, in *Novae and Related Stars*, ed. M. Friedjung (Dordrecht: Reidel), p. 123.
Colvin, J. D., Van Horn, H. M., Starrfield, S. G., and Truran, J. W. 1977, *Ap. J.*, **212**, 791.
Davidson, K., and Tucker, W. H. 1970, *Ap. J.*, **161**, 437.
Ennis, D., Becklin, E. E., Beckwith, S., Elias, J., Gatley, I., Matthews, K., Neugebauer, G., and Willner, S. P. 1977, *Ap. J.*, **214**, 478.
Ferland, G. J. 1977*a*, *Ap. J.* (*Letters*), **212**, L21.
———. 1977*b*, *Ap. J.*, **215**, 873.
———. 1977*c*, *Nature*, **267**, 597.
———. 1977*d*, *Bull. AAS*, **9**, 316.
Ferland, G. J., Lambert, D., and Woodman, J. 1977, *Ap. J.*, **213**, 132.
Ferland, G. J., Tomkin, J., and Woodman, J. 1976, *Nature*, **264**, 627.
Gallagher, J. S., and Ney, E. P. 1976, *Ap. J.* (*Letters*), **204**, L35.
Gallagher, J. S., and Starrfield, S. 1976, *M.N.R.A.S.*, **176**, 53.
Harmon, R., and Seaton, M. J. 1966, *M.N.R.A.S.*, **132**, 15.
Hummer, D., and Mihalas, D. 1970, *M.N.R.A.S.*, **147**, 339.
Hummer, D., and Seaton, M. 1964, *M.N.R.A.S.*, **127**, 217.
MacAlpine, G. M. 1976, *Ap. J.*, **204**, 694.
Malakpur, I. 1973, *Astr. Ap.*, **28**, 393.
McLaughlin, D. B. 1949, *Pub. Obs. Univ. Mich.*, Vol. **9**, No. 3.
McLaughlin, D. B. 1960, in *Stars and Stellar Systems*, Vol. **6**, *Stellar Atmospheres*, ed. J. L. Greenstein (Chicago: University of Chicago Press), p. 585.
Netzer, H. 1975, *M.N.R.A.S.*, **171**, 395.
Netzer, H., and Penston, M. V. 1976, *M.N.R.A.S.*, **174**, 319.
Osterbrock, D. E. 1974, *Astrophysics of Gaseous Nebulae* (San Francisco: Freeman).
Payne-Gaposchkin, C. 1957, *The Galactic Novae* (Amsterdam: North-Holland).
Peimbert, M. 1975, *Ann. Rev. Astr. Ap.*, **13**, 113.
Pottasch, S. 1959, *Ann. d'Ap.*, **22**, 412.
———. 1962, *Ap. J.*, **135**, 385.
———. 1967, *Bull. Astr. Inst. Netherlands*, Vol. **19**, No. 3.
Robbins, R. R. 1968, *Ap. J.*, **151**, 497.
Shields, G. A. 1974, *Ap. J.*, **191**, 309.
Starrfield, S., Sparks, W. M., and Truran, J. 1974, *Ap. J. Suppl.*, **28**, 247.
Strittmatter, P. A., *et al.* 1977, *Ap. J.*, **216**, 23.
Tomkin, J., Woodman, J., and Lambert, D. L. 1976, *Astr. Ap. Letters*, **48**, 319.
Young, P. J., Corwin, H. G., Jr., Bryan, J., and de Vaucouleurs, G. 1976, *Ap. J.*, **209**, 882.
Wiese, W., Smith, M., and Glennon, B. 1966, *Atomic Transition Probabilities*, Vol. **1** (*NSRDS-NBS 4*).
Williamon, R. 1977, *Pub. A.S.P.*, **89**, 44.

G. J. FERLAND: Department of Astronomy, University of Texas, Austin, TX 78712