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COMMENTS ON THE SPECTRUM OF NOVA SCUTI 1975

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ABSTRACT

Optical spectrophotometric observations of Nova Scuti 1975 obtained on 1975 August 2 and 31 (at 3 and 4 mag, respectively, below maximum) and a few near-infrared spectra provide a basis for a discussion of the emission spectrum. That lines from O I, [O I], [O II], [O III], N I, N II, [N II], N III, H, He I, and He II are most prominent indicates a wide range in density and degree of ionization within the nova. The data suggest that Hα and maybe Hβ are optically thick. He I λ3889 is optically thick, and the ratio of He I λ5876 to Hβ is quite high. An overabundance of He is possible but far from certain. Lines of N II are pathologically strong, a common but unexplained feature of novae. The problem of coronal lines in declining novae is reviewed. Although coronal emission is probably found in some cases, alternative identifications of N II λ6379, O I λ7886, or Mg II λ7890 are possible for emission features often attributed to [Fe X] λ6374 and [Fe XI] λ7892.

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

I. INTRODUCTION

Nova Scuti was first reported on 1975 June 15 at $m_v = 7$ by Wild (1975). Subsequently, a number of prediscovery observations became available, and a combination of all *IAU Circular* data has been used to produce the optical light curve in Figure 1. The oscillations during the decline are probably real, and the overall form of the light curve is reminiscent of moderately fast novae like DK Lac (Payne-Gaposchkin 1957; McLaughlin 1960).

Rosino (1965) has shown that decline rate is usually a better luminosity indicator than duration. From Figure 1 we estimate $\delta \approx 0.07$ mag day^{-1}, and the Asiago calibration by Rosino then gives $M_{\rm pg} \approx -7$. This luminosity is also reasonably consistent with the absorption-line expansion velocities $V \gtrsim 1000$ km s^{-1}

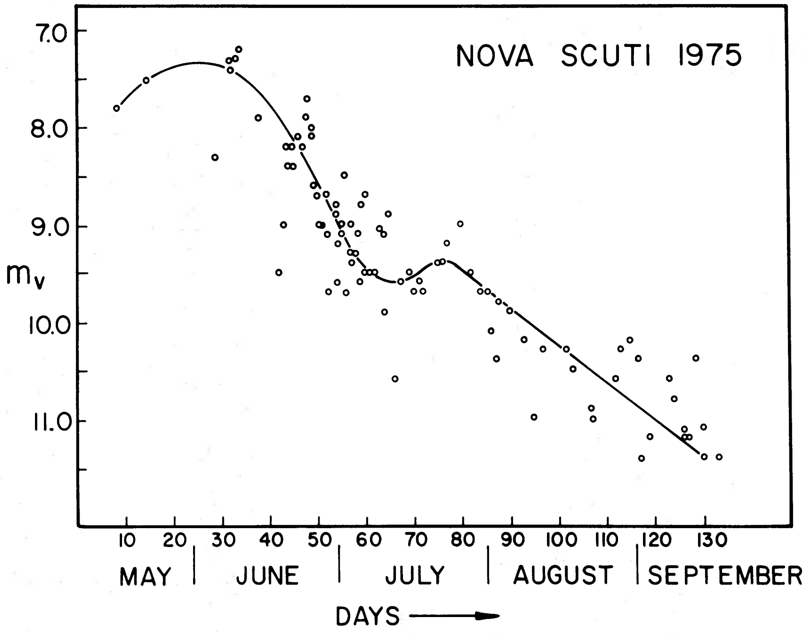

FIG. 1.—Optical light curve for Nova Scuti 1975 based on observations reported in the *IAU Circulars* during 1975. Since the individual points represent both eye and photoelectric magnitude measurements, some of the scatter about the illustrated mean light curve is probably due to differences in bandpass, standards, etc., and some due to real, short-term brightness variations by the nova.

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found in late June of 1975 (see McLaughlin 1960, Table 13). Nova Scuti 1975 is a normal classical nova.

There is relatively little spectrophotometry available for novae, and we therefore were fortunate to obtain spectrophotometric measurements of Nova Scuti 1975 made by D. E. Osterbrock at Lick Observatory and by J. Warner at Cerro Tololo Inter-American Observatory. A few uncalibrated near-infrared spectra from the University of Minnesota's O'Brien Observatory are also available. These data are extremely

TABLE 1

OBSERVED LINE INTENSITIES ($I(\mathrm{H}\beta) = 100$)

Observed Wavelength Å	Wavelength of first Identification	Primary Identifications ( ) = multiplet number	Intensity August 1-2 (Lick)	Intensity August 30-31 (CTIO)
3550:	3554	He I(34)?	P*	-
3720:	3727	[O II] (1F)	8:	-
3760b	3771/50	H11, H12, N III(11), O III(2)	10	P
3796	3798	H10, He II(5), O III(2)	4:	11
3834	3835	H9, [Fe V](3F)?, N II(41)?	13	26
3855	3858	He II(4), N II(41)?, [Ne III](1F)	-	2:
3887	3889	H8, He I(2), He II(4), [Fe V](3F)?	15	P
3971	3970	Hε, [Ne III](1F)	30	30
3997b	3995	N II(12)	8:	5
4031	4026	He I(18), He II(3), N II(2,61)	-	3
4065b	4069/76	[S II](1F)	8:	P
4102	4102	Hδ, N III(1)	45	67
4200:	4200	He II(3), O II 36, N III(6)	7:	-
4275:	4267	C II(6), [Fe II] blend	-	P
4344	4341	Hγ, [O III](2F)	67	150
4410:	4413	[Fe II] blend	P	-
4430b	4427	N II(56), N II(55)?	}30	-
4460b	4458	[Fe II] blend		-
4472b	4472	He I(14)	(7)	16
4525b	4511-24	N III(3)	14	18
4600b	4607	N II(5), N V(1)?, O II(15)	P	P
4640b	4634/41	N III(2), N II(5), C III(1), O II(1)	91	91
4686	4686	He II(1)	10:	34
4800	4803	N II(20)	P	P
4860	4861	Hβ	100	100
4932b	4922	He I(48), Fe II(42), [O III](1F)	17	97
4950b	4959	[OIII](1F)		
5006	5007	[O III](1F), He I(4), Fe II(42)	40	saturated
5045b	5048	N II(4)	P	10:
5170b	5169	Fe II(42), N II(66)	8:	13
5195b	5198	Fe II(49), [N I](1F)		
5270b	5268	O III(19), [Fe III](1F)?		
5322b	5317	Fe II(48,49), N II(36)?	7	7
5410:	5412	He II(2)	-	P
5485b:	5480	N II(29)	P	P
5597b	5592	O III(5)?	P	P
5680	5680/67	N II(3)	38	32
5755	5755	[N II]3F	104	47
5815	5812	C IV(1)?	P	P
5875	5876	He I(11)	13	38
5928b	5932	Fe II(47), N II(28)	P	-
5950b	5942-60	N II(28)	10	11
6100	—	?	P?	-
6162	6168	N II(36,60), He II8	P	P
6245	6243	N II(57), Fe II(74)	P	P
6300	6300	[O I](1F), [S III](3F)?	14	15
6370	6364	[O I](1F), Fe II(40), [Fe X](1F)?	11	23
6490	6482	N II(8), Fe II(?)	31	P
6570	6563	Hα, [N II](1F)	1000	saturated
6730	6731/17	[S II](2F)	P	-
7069	7065	He I(10)	10	-
7122b	7112-34	C II(20)?	10	-
7226b	7231/36	C II(3)	11	-
7247b	7254	O I(20)?		-
7326	7319/30	[O II](2F)	74	-
	Hβ/λ5350	continuum (arb units)	2.6	3.5:

*P indicates line is present but weak

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fragmentary. However, Nova Scuti 1975 was well behaved, and the known systematic behavior of moderately fast novae can be used to provide a framework for interpretation.

II. OBSERVATIONS

The Lick Observatory data were taken on 1975 August 2 by Osterbrock using the image-tube image-dissector system (Robinson and Wampler 1972) on the 3 m telescope Cassegrain spectrograph. A total of six scans were made, two covering the blue region λλ3520–5870, and four in the red region λλ5185–7610. Because of the large range in line intensities, blue spectra were made with both clear and 2.5 mag neutral-density filters. Red spectra required an additional measurement with a 5 mag neutral-density filter because of the strength of the Hα–[N II] blend. The observations were reduced to F_λ versus λ plots by correcting for instrumental response, wavelength nonlinearities, etc., following standard procedures outlined by Osterbrock and Miller (1975).

Fluxes of stronger lines were measured directly from the final plots with a planimeter. The major uncertainties arise from the difficulties in assigning continuum levels and in allowing for line wings, and not from errors in measurement. For a few weaker lines, an empirically determined calibration between flux and line base width times height was used. Line intensities relative to Hβ are given in Table 1.

Image-tube spectra having a dispersion of 118 Å mm^{-1} were obtained by Warner on 1975 August 31 using the Cassegrain image-tube spectrograph on the Yale 1 m telescope at CTIO. Two exposures differing by a factor of 2.65 were made of the nova, which allowed all but the strongest features to be measured. Because of a blue leak, the wavelength coverage is effectively limited to λλ3500–6600. The standard stars κ Aql and 29 Psc (Hayes 1970) provided a calibration of the relative response function, and a density-to-intensity conversion was made from simultaneous spot sensitometer plates. All of the plates were converted to density tracings by using a Joyce-Loebl densitometer at the University of Minnesota.

The response function as determined from four spectra of the standard stars agreed to within 10% over λλ3500–6600 but only repeated to about 20% near Hα because of problems caused by the blue leak. Since several categories of line profiles are present, it was necessary to measure more than peak intensities to find relative fluxes. Lines were therefore approximately modeled in intensity units, and areas were used to measure fluxes. The internal agreement between line ratios based on the two different exposures is only moderate, with typical variations of 15%. Again, line strengths are systematically affected by problems in defining the continuum. The final line ratios are given in Table 1, and the spectrum is illustrated in Figure 2. Note that all of the line ratios in Table 1 are subject to some ambiguity, as the spectral resolution of these observations was insufficient to allow a component-by-component intercomparison of lines. Since the two major shells in nova emission spectra may have quite different characteristics (Gallagher and Anderson 1976), the approach used here is not entirely satisfactory. Also, differential extinction across the nova can cause difficulties in interpreting line ratios (e.g., Sanyal 1974).

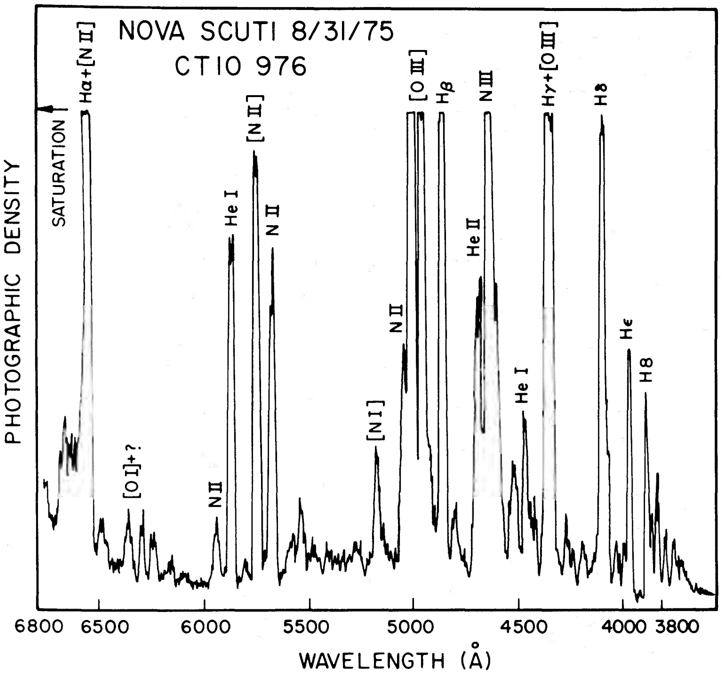

FIG. 2.—Density tracing of the more heavily exposed CTIO spectrum of Nova Scuti 1975. Major lines have been identified following Table 1.

TABLE 2

NEAR-INFRARED SPECTRA OF NOVA SCUTI

Wavelength	Identification and Wavelength	Line Strength-Eye Estimates			
		June 24-30*	June 28$^+$	July 18	August 3
6570	Hα 6563, [N II] 6548/84	strong	5	5	5
6680	He I(46) 6678	weak	0?	0	0
6725	[S II] 6719/30		0	0-1	0
7065	He I(10) 7065	weak	np?	1	1-2
7135	[A III] 7136		np?	1	1
7220b	Fe II(73) 7222, CII(3) 7230	present	np?	1	} 1
7240b	O I(20) 7254, C II(3) 7236		np?	1	
7325	[O II] 7319/30	present	2	3	3
7460b	N I(3) 7468, O I(55) 7480 Fe II(73) 7462		1-2	2	0
7780	O I(1) 7772-75	moderate	2	3	2
7890	O I(64) 7886, Mg II(8) 7877, [FeXI]?	weak	0	1	?
8220	N I(2) 8200/16/23	moderate	0-1	2	1
8260	unidentified		0?	1	0
8450	O I(4) 8446	strong	3-4	4	4-5

*Fehrenbach and Andrillat (1975)

$^+$ITT image intensifier; other spectra taken with a Varo image intensifier.

np = not present

Red and near-infrared spectra covering λλ6500–8500 with dispersion of 90 or 130 Å mm^{-1} were taken at irregular intervals with the Boro Spotz small Cassegrain spectrograph on the O'Brien Observatory 76 cm telescope. Initially, an uncooled, two-stage ITT 40 mm diameter fiber optics image intensifier with an S-20 cathode was used as the primary detector. In 1975 July it was replaced by a similar type of cooled Varo image intensifier having excellent response to 8500 Å. Major near-infrared emission lines and eye estimates of strength are listed in Table 2, and a sample spectrum is shown in Figure 3. Emission lines noted on a series of near-infrared spectra obtained in late June by Fehrenbach and Andrillat (1975) are included in Table 2 for comparison.

III. DISCUSSION OF THE SPECTRA

In the range of 3–4 mag below maximum, which is relevant for our observations of Nova Scuti 1975, novae display a complex variety of emission features. Prominent optical species usually include H(Balmer), He I, He II, N II, N III, [O I], [N II], [O III], and [Ne III]

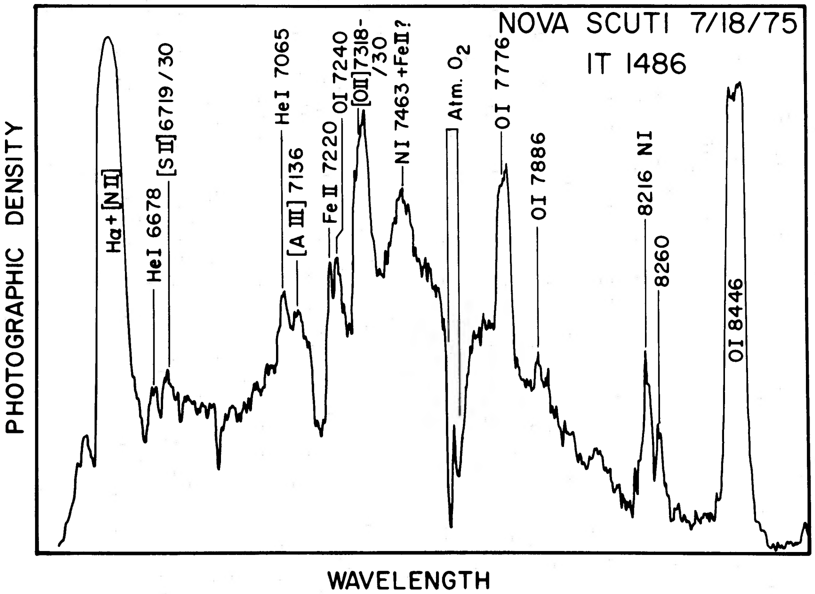

FIG. 3.—Density tracing of the 1975 July 18 near-infrared spectrum obtained with the O'Brien Observatory 76 cm telescope.

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(Payne-Gaposchkin 1957). The absence of [O II] λ3727 is due to collisional quenching, which is to be expected at the high densities in nova envelopes. The situation is further complicated for novae showing light curve oscillations during the decline, as the strength of high-excitation permitted features tends to be anticorrelated with optical brightness (Payne-Gaposchkin 1941, 1957; McLaughlin 1960). This suggests that we consider the envelope to consist of at least two zones: (1) a hot, high-density region near the stellar remnant which might behave like a dense stellar wind or extended atmosphere; and (2) a lower-density and cooler shell (McLaughlin 1960; Friedjung 1966; Nariai 1974; Sparks, Starrfield, and Truran 1976).

Given these complications, it is clear that the present data are hopelessly inadequate for the construction of even a rudimentary model. However, some characteristics of individual lines provide a useful basis for preliminary explorations of conditions in the nova. These are reviewed below.

a) H.—The Balmer-series decrement from Table 1 is quite pathological, e.g., $H\gamma/H\beta = 0.7$. This may be partially due to errors in measuring line areas, and we have therefore also determined the Balmer decrement from line heights alone using the Lick data (see Table 3), a procedure which should be valid for any set of lines with similar profiles. The Balmer decrement then appears more normal for $H\gamma/H\beta$ and $H8/H\beta$, but is still peculiar for the other series numbers. These lines are, however, quite likely to be blended with strong emission features, which are identified in Table 3. Thus, other than Hα, the hydrogen Balmer spectrum might be interpreted as what would be expected from case B recombination, although the simplifying assumption of a single component at one temperature and the lack of any good estimate for the correction for interstellar reddening clearly weaken this conclusion.

It is more likely that some or all of the Balmer lines are optically thick. In support of this view, we note that (1) the very strong O I λ8446 line (Table 2) could be indicative of pumping by Lβ (Strittmatter *et al.* 1977), which requires that at least Hα be optically thick; and (2) hydrogen emission strengths have been observed to be modulated during semiperiodic light oscillations in the nova V603 Aql (Payne-Gaposchkin 1941), which suggests that emission contributions from high-density regions can be important. If the H*n* line is observed to vary substantially on a time scale of *t* days, then $N_e \gtrsim [t\alpha_B(n)]^{-1}$. In the case of V603 Aql, Payne-Gaposchkin's (1941) data showed that Hδ had $t \approx 1$ day. Taking α_B from Osterbrock's (1974) Table 4.4, assuming $T = 10^4$ K, we have $N_e \gtrsim 1 \times 10^9$ cm^{-3}. Under these circumstances the Hβ line would be likely to have $\tau > 1$.

A further indication of high optical depth is the large $H\alpha/H\beta$ ratio. Although Hα is hopelessly blended with [N II], an approximate estimate of the relative contribution of [N II], I[N II], can be crudely obtained from the centroid wavelength of the blend, $\lambda_c = 6562.8 + 11.8I[\text{N II}]$. From the Lick scans, we find $\lambda_c = 6567$ and thus $I(H\alpha) \gtrsim 0.6I$. The combination $\log H\alpha/H\beta \gtrsim 0.8$ and $\log H\gamma/H\beta = -0.28$ would

TABLE 3

LINE RATIOS FOR INDIVIDUAL SPECIES

		LICK		CTIO	Case B		Comments
HI		Table 1	Line height	Table 1			
	H8	0.15	0.17	-	0.11*	0.11**	b HeI
	Hε	0.30	0.29	0.30	0.16	0.16	b [NeIII]
	Hδ	0.45	0.45	0.67	0.26	0.26	b NIII
	Hγ	0.67	0.53	1.50	0.47	0.48	b [OIII]
	Hβ	1.0	1.0	1.00	1.00	1.00	
	Hα	10 (7)	10	-	2.81	2.74	b [NII]
HeI	3889	$\lesssim$0.4(est)	-	-	0.83*	1.08**	b HI
	4471	$\lesssim$0.5:	0.6:	0.42	0.37	0.39	b [FeII]
	5876	1.00	1.00	1.00	1.00	1.00	
	7065	0.8	0.7	-	0.12	0.19	

* $T = 10^4$ $N_e = 10^6$ cm^{-3} from Osterbrock (1974)

** $T = 2 \times 10^4$ $N_e = 10^4$ cm^{-3} from Osterbrock (1974) then at face value require $\tau(\mathrm{H}\alpha) \gg 1$, if the Hα emission is all to arise from recombination.

An additional complication in understanding the Balmer decrement could arise, if Hα were in part collisionally excited in the high-temperature interior envelope of the nova. This should affect the line profiles; thus this possibility could be tested, if high-resolution line profiles were available for Hα and Hβ. Whatever its cause, the unusual Balmer decrement is not unique. Similarly large Hα/Hβ ratios were observed during the declines of Nova Herculis 1960 (V443 Her) (Meinel 1963) and Nova Herculis 1963 (V533 Her) (R. Bless, A. D. Code, and T. Houck, private communication), although in both of these novae the Balmer decrement approached normal recombination values as the nebular stage progressed.

b) He I *and* He II.—Emission from both He I and He II increased relative to Hβ during 1975 August. Part of the general trend in which the mean level of ionization was rising, this increase showed that the expected postmaximum shift of luminosity into the ultraviolet had occurred (Gallagher and Starrfield 1976). In the Lick data He II was too weak and blended with λ4640 to measure; only the He I triplets λ5876 and λ7065 were strong enough to measure with confidence. He I λ4471 is present but badly blended. In the CTIO data both λ4471 and λ5876 were relatively pronounced and unblended. Line ratios and case B recombination predictions are summarized in Table 3.

Both data sets are consistent with $I(4471)/I(5876) \approx 0.4$, which is quite close to the expectations from simple recombination theory (Osterbrock 1974). However, λ3889 is too weak. [We have estimated $I(3889, \mathrm{He\ I}) \approx 0.33 I(3990)$ from the strength of Hβ; however, even if *all* the λ3990 is due to He I, the line is still deficient relative to the case B predictions.] On the other hand, λ7065 is considerably stronger than expected. This pattern of line intensities is characteristic of the effects of self-absorption from the metastable $2\,^3S$ level (Robbins 1968). When we assume a local velocity of 50 km s^{-1} within the ejecta (Gallagher and Anderson 1976), then the ratio of differential expansion to thermal velocity is $\gamma = v/v(\mathrm{thermal}) > 5$. The models tabulated by Robbins (1968) for $\tau(3889) = 75$, $\gamma = 5$, and $T = 2 \times 10^4$ give $I(7065)/I(5876) = 0.7$, in good agreement with our observations. This model also gives $I(4471)/I(5876) = 0.35$. As this ratio is almost independent of optical depth, the observations are consistent with low interstellar reddening.

From Table 1 we see that, for the Lick and CTIO data, $I(5876)/I(\mathrm{H}\beta)$ is 0.1 and 0.4, respectively. Since it is unlikely that reddening is very important, this ratio and $I(4686)/I(\mathrm{H}\beta)$ may directly reflect the abundance of helium relative to hydrogen. Using the standard techniques outlined by Osterbrock (1974), we have derived the *indicative* helium abundances given in Table 4. It would appear that helium is significantly overabundant relative to hydrogen in Nova Scuti 1975. The increases in the apparent amount of helium during August are most likely due to changes in the relative volumes occupied by the relevant He and H ionization zones. *Unfortunately, at this time we cannot interpret the results in Table 4 as rigorous evidence for an excessive abundance of helium.* Even though [He/H] is rather insensitive to temperature, large optical depths or radiative-transfer effects in either line would invalidate the assumed proportionality between emission strength and total number of ions. While the optical thickness of Hβ is uncertain and the chances of variations in He I λ5876 strength due to large column densities are small (Robbins 1968), a longer sequence of observations would be needed to assure that the emitting volumes are behaving in an optically thin fashion. At the epoch of these observations, it is also conceivable that some components of the lines are collisionally excited, which would also nullify the simple abundance analysis.

c) N II *and* N III.—Both N^+ and N^{++} are present in the nova shell. The N III spectrum is most evident from the λ4640 emission blend (which also contains contributions from C III, O II, and N II), although λ4097 and λ4103 are certainly also present. It is likely that the great strength of N III λ4640 is due to the action of fluorescence with O III through the Bowen

TABLE 4

POSSIBLE HELIUM ABUNDANCES RELATIVE TO HYDROGEN*

Date	I(λ5876)/I(Hβ)	I(λ4686)/I(Hβ)	$n(\mathrm{He}^+)/n(\mathrm{H}^+)$	$n(\mathrm{He}^{++})/n(\mathrm{H}^+)$	n(He)/n(H)
August 2, 1975	0.13	≲0.1	0.09	≲0.009	~0.1:
August 31, 1975	0.38	0.34	0.27	0.03	≳0.3

*Assumes recombination at $T = 10^4$K and $N_e = 10^6$ using rates given by Osterbrock (1974). Note that the line intensities could be affected by collisional excitation or transfer effects; thus the abundances in this table may not be reliable (see text).

mechanism and starlight excitation (Swings 1948). The presence of large intensities in N III is then good evidence for a strong stellar continuum near λ374 and for the existence of substantial velocity gradients to overcome the effects of self-shadowing. Since λ4640 emission is virtually a trademark of novae during both the active and postoutburst phases, it would be useful to have a more quantitative understanding of N III emission. Observations of the time dependence of the near-ultraviolet O III resonance fluorescence in novae could prove quite interesting in this regard.

It is possible to place some very rough limits on starlight excitation of N III. As Hβ may be optically thick, the ionizing flux from the star $F_\lambda{}^*$, for $\lambda < \lambda_0 = 912$ Å, will be related to the Hβ flux $F(\mathrm{H}\beta)$ in a steady-state case by

$$\int_{\lambda_0}^{0} F_\lambda{}^* d\lambda = \eta 40 F(\mathrm{H}\beta) \frac{912}{\langle \lambda_0{}^* \rangle}\,, \qquad (1)$$

where $\eta \geq 1$ and $\langle \lambda_0{}^* \rangle$ is the effective wavelength of the ionizing continuum. Now assume a fraction ϵ of the λ4640 emission results from conversion of stellar continuum photons over a rectangular Doppler profile of width $\Delta\lambda_0 \approx 2000$ km s^{-1}; then

$$F^*(374)\Delta\lambda_0 \approx 12F(4640)\,. \qquad (2)$$

From Table 1, $F(4640) \approx 0.9F(\mathrm{H}\beta)$. As an illustrative example, we take $\eta = 5$, $\epsilon = 1$, and $\langle \lambda_0{}^* \rangle = 450$ Å, in which case the total ionizing flux is ~50 times the flux over $\Delta\lambda_0 \approx 3$ Å near λ374 that is required to produce the N III. Thus it does not appear unreasonable, considering the high fluxes which occur in hot stars near the N III edge, that starlight excitation can be important in novae—although, of course, contributions from the Bowen mechanism and recombination may also be substantial.

In any case, a high-temperature region ($T > 50{,}000$ K but less than 100,000 K, as N V is absent) seems unavoidable. This is not an unusual temperature estimate for a declining nova (Gallagher and Starrfield 1976; see also Gallagher 1977) and suggests that a plateau luminosity stage has followed visual maximum, as has now been directly observed in several novae.

Rich N II emission is also common in novae as a part of the nitrogen-flaring phenomenon (Payne-Gaposchkin 1975). For example, prominent N II lines were seen in spectra of the fast and moderate novae V603 Aql (Wyse 1939), CP Pup (Sanford 1945), DK Lac (Wellmann 1951), V446 Her (Meinel 1963), and V533 Her (Andrillat and Collin-Souffrin 1974) and are also clearly in evidence in Nova Scuti 1975. The physical processes or conditions which lead to enhanced N II emission are not understood. In particular, the strength of N II λ5678 [$\sim\frac{1}{3}I(\mathrm{H}\beta)$] is impossible to reconcile with any normal recombination model. From the available data, it does not appear that dielectronic recombination leading to λ5678 emission is especially likely. This quandary led Meinel (1963) to suggest that the N II spectrum is collisionally excited; but as the lines are ~20 eV above the ground state, a rather hot region would be required. However, Grandi (1976) has proposed that the relatively high intensities of some of the N II triplets in the Orion Nebula [$\sim 10^{-3}I(\mathrm{H}\beta)$] may be the result of resonance fluorescence of the $4s\,{}^3P^o$ term of N II by the He I $1s^2\,{}^1S$–$1s8p\,{}^1P^o$ λ508.7 recombination line. It is uncertain whether this process could produce N II lines as strong as those in novae, although the appropriate triplet transitions are all present. But until the physics of N II emission in novae can be unraveled, it is impossible to use this obviously unique characteristic as a tool to explore the late-decline phase. Another hint that something peculiar is happening is the similarity between the time-dependent behaviors of He I and N II in Nova Herculis 1960 (V443 Her) (Meinel 1963); this would seem to support the He I fluorescence mechanism, and it also further reinforces the necessity of proceeding with caution in interpreting the strength of He I emission solely in terms of an abundance anomaly.

d) Other permitted lines.—Aside from lines of N II, N III, H, He I, and He II, only weak permitted features which could be due to C I, O II, O III, or Fe II are seen in the optical region. Infrared spectra, however, reveal the presence of some N I emission and strong O I features through the beginning of 1975 August (see Table 2). Thus, although the degree of ionization is steadily increasing, neutral areas are evidently important rather long after the nebular stage has been entered. It would be useful to establish whether we are dealing with a radial ionization dependence in which an H II region is expanding into a neutral shell (cf. Strittmatter *et al.* 1977; Bosma 1972; Ferland 1977) or with a density within each shell of sufficient nonuniformity that lumps of neutral matter remain embedded in a volume of ionized gas. To this end, systematic observations of the time dependence of the infrared λ7772 and λ8846 O I lines, as compared with nebular features in different types of novae, would be quite valuable (see Strittmatter *et al.* 1977). It is also of importance to try and estimate the relative masses of material involved in the neutral and ionized phases, as the strong O I could be arising from a relatively small mass fraction of high-density gas during the early nebular stage.

In particular, if the radial ionization structure suggested by Ferland (1977) for Nova Cygni 1975 (V1500 Cyg) is correct, then it may be necessary to reexamine the processes which inhibit extensive dust condensation in fast novae. Gallagher (1977) has suggested that the formation of an H II region prevents the production of grains. However, the ionization time scale found for his very simple model used in conjunction with the study of grain formation is short compared with the observed duration of O I and [O I] emission. For example, in the case of V1500 Cyg, the O I remained prominent for about 100 days (Strittmatter *et al.* 1977) as compared with the estimated ionization time of 40 days given by Gallagher (1977). If the neutral material is in subcondensations (as in planetary nebulae), then the dust model probably remains reasonable. Since the condensations fill a small solid angle, even if dust does form in the neutral regions, the infrared luminosity would be low. This type of model might be able to produce the late, low-luminosity thermal infrared excess found in Nova Cygni 1975 by Ennis *et al.* (1977).

e) High-excitation forbidden lines?—The ratio of [O I] λ6300 to [O I] λ6364 is set by the relative Einstein *A*-values of 3–1. As can be seen from Table 1, the strength of the λ6364 feature is far too strong to be due to [O I] alone. Four blends with [O I] are at least feasible: Fe II λ6369, Si II λ6347 and λ6371, [Fe X] λ6374, and N II λ6379. Because of the extreme velocities in novae, it is exceedingly difficult to make a positive identification on the basis of wavelength alone. The most generally accepted identification for the feature contaminating [O I] λ6364 is [Fe X] λ6374 (e.g., Payne-Gaposchkin 1957; Bloch and Chalonge 1965; Ferland, Lambert, and Woodman 1977), which in some cases may be correct; but the possibility of confusion does exist. Since this point is of interest in terms of a rather understudied and important aspect of novae—i.e., the presence of very hot ($\sim 10^6$ K) gas soon after maximum (Grasdalen and Joyce 1976)—it is crucial that the identifications of [Fe X] and other coronal lines be firmly established.

Ferland *et al.* obtained digital, high-spectral-resolution coudé scanner data for the nova V1500 Cyg and were able to subtract the [O I] contribution from the λ6370 blend, using [O I] λ6300 to determine the profile and strength. These high-quality observations conclusively establish that Si II and Fe II cannot be the contributing lines in V1500 Cyg, especially during the later phases. Ferland *et al.* therefore strongly conclude that [Fe X] has been detected. The possible role of N II is not discussed, although N II does not seem to have been particularly strong in Nova Cygni 1975.

However, in other instances where the spectral resolution and photometric quality were lower, more details of the character of the rest of the spectrum are available. In the cases of V603 Aql (Wyse 1939), CP Pup (Sanford 1945), CP Lac (Wyse 1936), V443 Her (Dufay, Bloch, and Chalonge 1965), V533 Her (Bloch and Chalonge 1965), and Nova Scuti 1975, N II emission was prominent during the decline when possible [Fe X] λ6374 was first identified. Although N II multiplet (2), which gives rise to the λ6379 line, is an intercombination transition, the line is strong in laboratory spectra. Furthermore, as the excitation mechanism which accounts for the N II emission is unknown, one cannot state with any certainty *a priori* what the relative N II line strengths should be. Thus a conservative position is that N II λ6379 may offer a plausible alternative to [Fe X]. However, we wish to emphasize that the presence of a N II blend with [O I] also cannot be rigorously demonstrated with any of the available data; it is likely that coronal lines are seen in some instances.

An argument for the presence of [Fe X] is the existence of emission features coincident with other coronal lines such as [Fe XI] λ7892. Here confusion with O I λ7886 or Mg II λ7890 is possible. Since O I λ7886 arises from a doubly excited state, this line is not likely to be produced in an astrophysical situation (Grandi 1977). Whatever its identification, the λ7890 feature is probably present in the August 3 spectrum of Nova Scuti 1975 as well as in that of Nova Serpentis 1970 (FH Ser) (Ciatti and Mammano 1972) and on O'Brien Observatory spectra of Nova Vulpeculae 1976 at times when the [O I] ratio appears normal. The presence of a noncoronal contributor thus appears likely. During the decline and early transition it is possible that the strength of Mg II λ7890 could be enhanced through fluorescence by H I Lβ (J. Black, private communication), as has been proposed by Grandi and Phillips (1977) to explain the strong λ2950 emission seen in quasars. This model also predicts that Mg II λ2934 would be present at about $\frac{1}{4}$ the strength of Mg II λ2800, which appears to be marginally inconsistent with ultraviolet spectra of FH Ser for the 1970 mid-March period when λ7890 was seen (see Gallagher and Code 1974). Therefore, the proper identification of the λ7890 feature is at present uncertain, as [Fe XI], O I, and Mg II all have some disadvantage in at least one nova.

IV. SUMMARY AND CONCLUSIONS

At 3–4 mag below visual maximum, the emission spectrum of Nova Scuti 1975 was dominated by lines arising from neutral through doubly ionized H, He, N, and O. From the integrated strengths of the lines we have found the following:

1. The Balmer decrement does not agree with predictions of case B recombination—at least for the Hα/Hβ ratio, which is ~10. This and the presence of pronounced O I λ8446 imply that Hα and perhaps Hβ are optically thick. The decrement for higher series members is difficult to determine, owing to blending with other lines, but seems in reasonable agreement with recombination. At face value, the data suggest that the amount of interstellar extinction is not extremely large. It is also possible that the use of integrated line ratios, rather than of component-by-component ratios for each line, has affected the analysis.

2. The ratio of He I λ4471 to He I λ5876, which is relatively insensitive to effects of optical depth, is also close to theoretical values. Since λ3889 is weak and λ7065 is strong, at least the λ3889 line is optically thick (Robbins 1968). From the ratio of He II λ4686 to He I λ5876, we find that the fraction of He^{++} increases relative to He^{+} during our observations. If the strengths of He I and He II lines as compared with Hβ are interpreted as being purely indicative of abundances, then He is overabundant and $n(\mathrm{He})/n(\mathrm{H}) > 0.3$. The summary of available determinations of the He content of nova ejecta given by Collin-Souffrin (1977) has a mean value of $n(\mathrm{He})/n(\mathrm{H}) = 0.3 \pm 0.15(\sigma)$. Thus it is possible that nova ejecta are rich in He. However, the critical λ5876 or Hβ line ratio may be confused by effects from large optical depths or by unusual line-formation conditions. Further observations of novae that are well into the nebula stage (when the gas is approaching a steady state) are needed to confirm the possibility of a high helium content.

3. The strong N III λ4640 feature, if excited by the Swings (1948) continuum pumping mechanism, requires an exceedingly intense source of photons near 374 Å, which seems almost inconsistent with the hydrogen line strengths. This difficulty would be eased, if the N III originated in a very hot region, presumably near the nova core, where H recombination would be inefficient, and if O III Bowen fluorescence provided a substantial contribution to the line strength. The presence of a hot and presumably luminous remnant is clearly required to produce the observed N III, He II, and [O III] lines. Nova Scuti 1975 seems to have experienced the normal shift of luminosity to ultraviolet wavelengths during the visual decline (Gallagher and Starrfield 1976).

4. Lines of N II, especially N II λ5678, are very strong relative to H and He. It is not clear whether the physics of this common characteristic of novae are understood. It seems probable that some pumping mechanism, such as that suggested by Grandi (1976), or an enhanced recombination rate are involved. Meinel (1963) noted a similar problem in the nova V443 Her and suggested that the N II lines might be collisionally excited.

5. A wide range in state of ionization is indicated by, for example, the simultaneous presence of [O I] and [O III], while the coexistence of O I and [O I] shows that there is also a large density contrast.

The trend during the observations is toward an increased level of ionization. While the lines of O I and [O I] are quite pronounced, it does not necessarily follow that the mass fraction of neutral matter is large. The O I lines may be produced by a combination of fluorescence and recombination, while [O I] may also be enhanced by the presence of high-density concentrations within the ejecta. Further work on the spatial and ionization structure of postnovae through a comparison of line profiles (Gallagher and Anderson 1976) would be worthwhile.

6. Emission features at λ6370 (blended with [O I] λ6364) and λ7890, which may be identified with [Fe X] and [Fe XI], are seen. In this and several other cases, alternative identifications with N II λ6379 and an uncertain noncoronal feature near λ7890 (such as Mg II or O I) are at least feasible. Thus, for most novae, the identification of optical coronal lines during the early nebular stage should be regarded as mildly tentative.

We have found that, despite the richness of the emission spectrum, relatively little quantitative information is obtained from a limited study of line strengths. Although the situation would be improved, if denser time coverage and especially if higher spectral resolution were available (which would allow line profiles to be used), the major deficiency lies in a lack of understanding as to how the emission lines are produced. Thus an emphasis on time-dependent models would be most useful. It is also evident that, until such models are available, it would be unwise to assume that peculiar line ratios in declining or transition-stage novae are necessarily associated with anomalies in abundances.

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