SPECTROSCOPIC OBSERVATIONS OF NOVA V443 SCUTI 1989

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ABSTRACT

Nova V443 Scuti 1989 reached its maximum, of visual magnitude ~7.5, very likely on 13–14 September 1989 (JD 2447 783) displaying in its early decline brightness fluctuations of relatively large amplitude with a periodicity of about 17^d. Spectroscopic observations of the nova were carried out at Asiago, mostly with the CCD array, in October and November 1989, and after the period of seasonal invisibility, from March to July 1990. In October the spectrum was characterized by the presence of the Balmer emission lines and by those of Fe II, Na I, Ti II, O I, N II accompanied by two systems of displaced P Cyg absorptions, having an average velocity of about − 710 and − 1460 km s^{-1}. The transition phase took place in November, with the appearance of [N II] 5755 and [O II] 7319 − 30 and with the [O I] 6300 − 6364 flash. In March 1990, the nova was found in the nebular phase with wide emission lines of H, He I, He II, and collisionally excited lines of [N II], [O II], [O III], and [Ne III]. From April to July, the degree of ionization having further progressed, forbidden lines of Fe VI, Fe VII, A III, A IV, A V, Ca V, and possibly also of Fe X, emerged. The final part of this work has been devoted to the discussion of the observational data, with particular attention to the amount of reddening ($E_{B-V} = 0.30$), the anomalous Balmer decrement, the temperature of the central source of ionization and the problem of the helium content.

1. INTRODUCTION

Nova Scuti 1989 has been included in the program of systematic observations of normal and recurrent novae carried out at Asiago since 1958. The purpose of this program is that of determining light curves and spectral evolution of the novae after the outburst and in the course of the nebular phase. In spite of the facilities offered by the modern techniques and by the recent theoretical insights, many novae are disregarded soon after the announcement of their discovery and are lacking photometric and spectroscopic data. We are trying to fill, in part at least, this gap.

2. LIGHT CURVE

Nova Scuti 1989, of ~10.5 mag still rising, was discovered by Wild (1989) on September 20 in a dense stellar region of the Scutum Cloud, where several other novae have been observed in the past years. McNaught (1989) determined its position (R.A. = $18^h46^m58\overset{s}{.}11$; Dec. = $-6°14'44\overset{''}{.}88$; 1950) remarking that the prenova was not visible in the POSS, nor in other sky surveys (Eso, UK Schmidt, etc). Neither is it recorded in some Asiago plates of the region taken from 1970 to 1978 with the 67 cm Schmidt telescope (limiting magnitude of ~19).

The light curve of the nova, reproduced in Fig. 1, has been obtained by plotting the visual magnitudes published in the IAU Circulars from September to December 1989, mostly eye estimates made by AAVSO observers, with a few derived from Kodak T-400 films (McNaught 1989). Also some V photoelectric magnitudes (Landolt 1989; Monella 1989) and CCD observations are represented in Fig. 1. All are indicated with black points, while small triangles denote a few premaximum *pg* magnitudes in the rising branch of the light curve (Wenzel 1989).

Although the observations are rather heterogeneous, the light curve of the nova remains fairly well defined. Unfortunately there is a gap of one week in the observations, from JD 244 7778 to 7786, just in the period when the maximum was probably reached. By looking to the light curve, however, it appears very likely that the maximum was attained on September 13–14, with visual magnitude of ~7.5 (crossed circle in Fig. 1). It was followed by a steep decline to 11.2 mag, then the nova underwent large brightness fluctuations, with a semiperiodicity of about 17^d, rising to secondary maxima on October 2 ($m_V \sim 9.5$), October 17 ($m_V \sim 9.4$), and November 3 ($m_V \sim 11$). The amplitude of these fluctuations decreased in November and nearly disappeared during the nebular phase. Visual observations made by Boattini (1990), Pearce (1990), and Schmeer (1990) in March and April indicate that the nova was slowly declining from 12.9 mag. Later, from some Schmidt plates obtained at Asiago on July 19 and 20, we derived, by comparison with the standard stars of the galactic cluster M11 (Johnson *et al.* 1956), very close to the nova, the following magnitudes: $V = 14.8$ and $B = 15.20$. From these observations it was possible to ascertain that the decline of the nova, from 10 December 1989 ($m_V = 12.0$) to 20 July 1990 ($V = 14.8$), was nearly linear at a rate of 0.013 mag/d. The last observations have also shown the presence of a faint star of $V \sim 15.3$ about 8–10 arcsec northeast of the nova.

The rather complex light curve of the nova during the first months after maximum is somewhat alike to that of V400 Per and V373 Sct (Rosino 1978): however, since the star is not visible in the POSS, its total amplitude must have been larger than in these two novae, possibly around 13–14 mag.

In consequence of the brightness fluctuations the determination of reliable values of the rate of decline from maximum is very uncertain. In order to obtain at least an approximate value, we have traced in Fig. 1 a smooth light curve (dashed line), disregarding the brightness oscillations and taking the corresponding average magnitudes (circles). The time employed by the nova to drop 2 mag below the visual maximum has been in this approximation: $t_2 = 17^d$, corresponding to a rate of decline of 0.12 mag/d. Times of decline can also be obtained undirectly using some semiempirical relations of t_n with the expansion velocities derived from the

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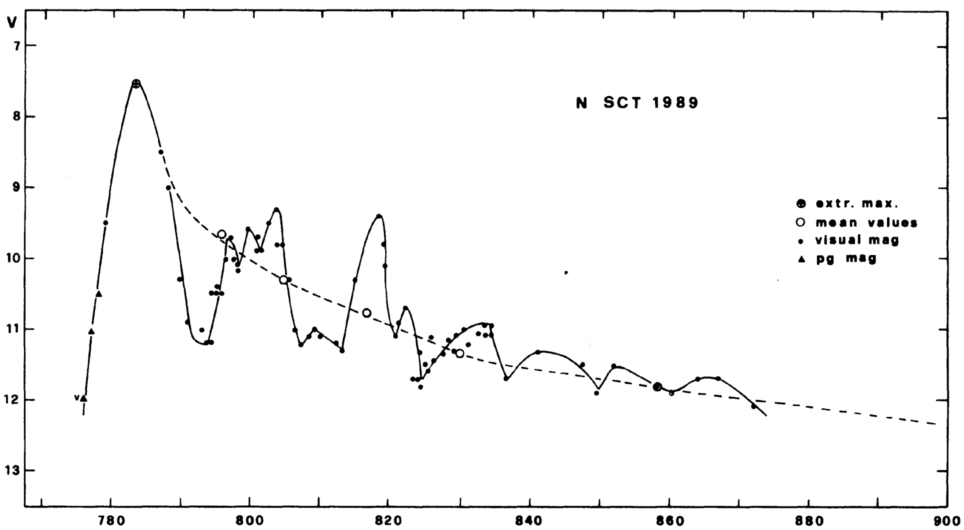

FIG. 1. Light curve of Nova V 443 Scuti.

principal and diffuse-enhanced systems (Warner 1989). We have found $t_2 = 28^d$ and, respectively, 23^d, finally adopting the mean value of the three determinations, $t_2 = 22\overset{d}{.}7$ and d_2 (rate of decline) = 0.088 mag/d. The star can therefore be classified at the limit between fast and moderately fast novae.

Some $B - V$ color indices of the nova have been determined between September 25 and October 8. Photoelectric observations carried out by Landolt (1989) on September 25.0, gave $B - V = +0.49$, but some days later, after the nova had risen to a secondary maximum, Monella (1989) using a photoelectric photometer found, from September 27.8 to October 2.8 values of $B - V$ from $+0.15$ to $+0.27$. Other determinations, of lower weight, gave: $+0.35$ (October 5.8) and $+0.28$ (October 7.8). Finally, an independent value of the color index was derived from a CCD spectrum of the nova taken at Asiago on October 6, comparing the intensity fluxes of the continuum at 4000–4950 Å and 5000–6000 Å. After reduction of the data to the B, V system, it has been found: $(B - V) = +0.4$, in fairly good agreement with the precedent values. In conclusion we adopted as mean weighed value of the color index of the nova from September 25 to October 8: $+0.35 \pm 0.12$.

3. SPECTROSCOPY

CCD spectra of the nova have been taken at Asiago with the Boller and Chivens spectrograph at the 1.82 m telescope, soon after the discovery, from September 1989 until nowadays (July 1990). Whenever possible, they were photometrically calibrated mostly with the standard star Kopff 27, and occasionally also with Feige 25 and Epsilon Aqr (Stone 1977; Taylor 1984) and reduced with the IHAP package. Other spectra, secured occasionally with the prism spectrograph of the 1.22 m telescope, were digitized with the PDS spectrodensitometer and then reduced with IHAP to relative intensity fluxes. The available spectroscopic material is listed in Table 1. The successive columns give: Date (UT); JD; phase (having assumed as date of maximum: September 13.5 = JD 244 7783); telescope; spectrograph; detector; effective spectral range; resolution.

3.1 Journal of Observation

1989 September 24. The first spectrum that we were able to obtain, about 10 days after maximum, was characterized by the presence of emission lines of H I, Fe II (mult. 42, 48, 49, 73, 74), N II (mult. 3, 63), Na I 5890–5896, O I 7775 Å. At this phase the lines were rather wide, with an average FWZI of 1720 km s^{-1}. The degree of excitation was moderately high. The suspected presence of He I 5876 and of the N III blend at 4640 Å (Barbon & Rosino 1989) was not confirmed after a more careful analysis of the spectrum. No clear evidence of P Cyg absorption lines was observed.

1989 October 5–6. The CCD spectra obtained on October 5 and 6, 21–22 days after maximum, when the nova, of visual ~10.5 mag, was declining to its second minimum, show a very significant change: the presence of deep P Cygni absorption lines of the principal and diffuse-enhanced systems (Fig. 2). The spectra displayed Balmer emission lines (up to H13) and bright lines of Fe II (present with most of its multiplets), N II, O I, Na I, Ti II, with blueshifted P Cyg absorptions. Forbidden lines of O I (at 5577, 6300, and 6364 Å), were also recorded.

In Table 2 the first column gives the observed wavelengths of the emission lines. The blue sides of most of these lines are partly cut by P Cyg absorptions and therefore their centers appear more or less displaced towards the red. Taking into account this and other minor effects (double peaks, blends) it has been possible to determine in most of the cases the laboratory wavelengths, the contributing atoms or ions, and the multiplets. They are reported in columns 2–4. The successive columns give the absolute fluxes of the emission lines (or blends of lines) relative to Hβ, on October 5–6 and November 8, measured in ergs cm^{-2} s^{-1}. The last column makes reference to the Notes to Table 2.

The wavelengths of the P Cyg absorptions, observed on October 5–6, and the corresponding radial velocities, are also reported in Table 2, columns 1–2, in italics. The average velocities of the two absorption systems are:

$$\text{October 5–6: } \langle V_1 \rangle = -700 \pm 60 \text{ (s.d.) km s}^{-1}$$

(principal system),

TABLE 1. Spectroscopic observations.

Date (UT) 1989 -90	JD 244	Phase	Tel m	Spectr.	Detect.	Range nm	Resol. Å
Sep 23.80	7793.3	+10	1.22	A-VI	S-20	380-850	3
Oct 4.80	804.3	+21	1.82	B&C	CCD	480-680	4
Oct 5.72	805.2	+22	1.82	B&C	CCD	360-680	4
Oct 10.85	810.4	+27	1.22	A-VI	S-20	410-850	3
Nov 7.77	838.3	+55	1.82	B&C	CCD	385-495	4
Nov 13.78	844.3	+61	1.22	A-VI	S-20	380-850	3
Nov 14.74	845.2	+62	1.22	A-VI	S-20	380-850	3
Nov 16.73	847.2	+64	1.22	A-VI	S-20	380-850	3
Nov 16.76	847.3	+64	1.22	A-VI	S-20	380-850	3
Nov 24.73	855.2	+72	1.82	B&C	CCD	700-825	4
Mar 21.17	971.7	+188	1.82	B&C	CCD	400-510	4
Apr 3.42	984.9	+201	1.50	B&C(ESO)	CCD	450-540	2
Apr 4.41	985.9	+202	1.50	B&C(ESO)	CCD	420-610	4
Apr 5.42	986.9	+203	1.50	B&C(ESO)	CCD	610-800	4
Apr 12.09	994.6	+210	1.82	B&C	CCD	375-780	20
Apr 12.09	994.6	+210	1.82	B&C	CCD	375-780	20
Apr 12.10	994.7	+210	1.82	B&C	CCD	375-780	20
May 8.05	8019.6	+236	1.82	B&C	CCD	380-600	10
MAY 8.10	019.6	+236	1.82	B&C	CCD	580-800	10
MAY 31.06	042.6	+259	1.82	B&C	CCD	590-690	4
JUL 8.00	080.5	+267	1.82	B&C	CCD	375-780	20
JUL 13.00	085.5	+272	1.82	B&C	CCD	375-660	18
Jul 13.04	085.5	+272	1.82	B&C	CCD	530-778	18

$\langle V_2 \rangle = -1460 \pm 80$ (s.d.) km s^{-1}

(diffuse enhanced).

The strongest emission lines in the spectrum were Hα, Hβ, and Fe II mult. 42 at 5018, 5169, and 4922 Å. From the FWHM of unblended emission lines, an average expansion velocity of the ejecta $\langle V_{EX} \rangle = 1680 \pm 40$ km s^{-1} has been derived.

1989 October 11. The spectrum of the nova a few days later, at its secondary minimum (visual ~11.1 mag), was nearly the same, as in October 5–6. In the infrared, however, were visible, in addition, strong O I lines at 7775 and 8446 Å.

1989 November 8–17. It was possible to take another CCD spectrum of the nova, covering the range from 3850 to 4920 Å (Fig. 3), on the night of November 7.8, about one month after the precedent one. The nova had declined to visual magnitude of ~11.5, and, as shown in Table 2, the absolute intensities of the emission lines were in general weaker than in October. Some lines, as those of Ti II were no further perceptible and most of the Fe II lines appeared somewhat weakened with respect to Hβ. At the same time, however, was observed the emerging of new lines of O II, N II, and possibly also N III, indicating an increase of the degree of excitation of the gas in expansion around the nova.

The emission lines were still flanked by deep P Cyg absorptions with an average radial velocity $\langle V_4 \rangle = -1790 \pm 60$ (s.d.) km s^{-1}. There was also a residual of the old principal system with three lines, barely visible,

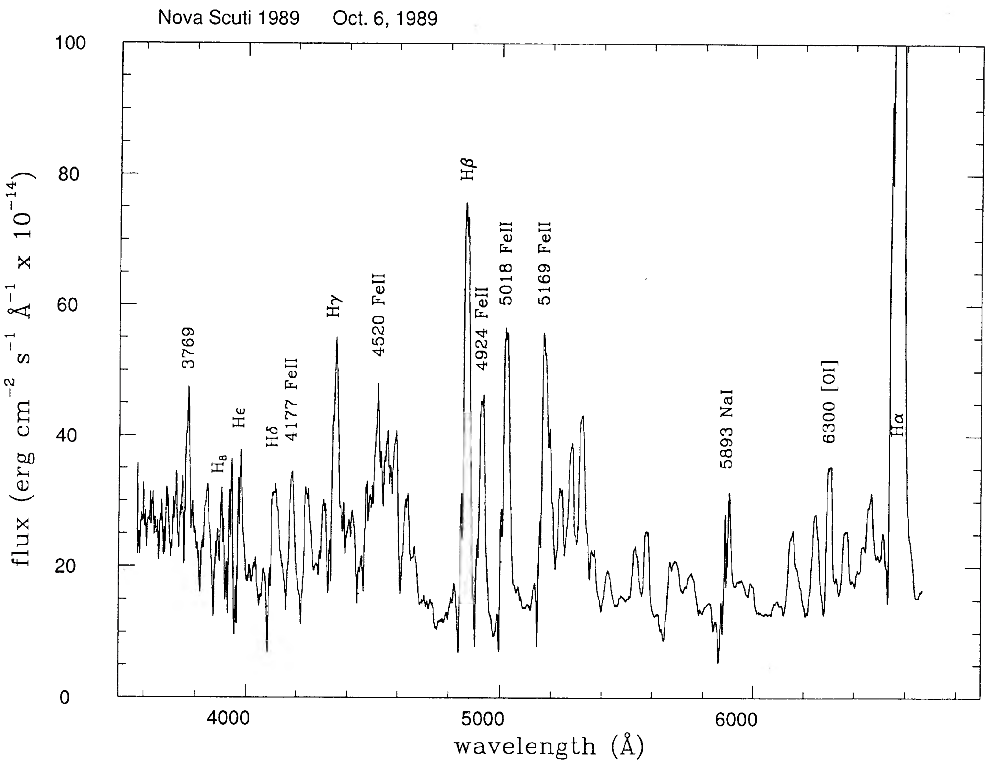

FIG. 2. CCD spectrum of the nova on 6 October 1988.

giving a velocity $\langle V_3 \rangle$ of about -1000 km s^{-1}. Wavelengths and velocities are reported in italics, in Table 2 (columns 3 and 4).

The spectra taken with the prism spectrograph at the 1.22 m telescope in the nights from November 14–17 do not allow the determination of absolute fluxes, but give an overall view which extends to the yellow–red spectral region (Fig. 4) the informations obtained from the CCD spectrum on November 8. Noteworthy were: the flaring of the [O I] doublet at 6300–6364 and the appearance and rapid strengthening of the auroral line of [N II] 5755, at about the same time as that of [O II] 7319–30 in the near infrared (Sec. 3.2).

The strongest emission lines after Hα in the spectral interval 5000–6600 were: Fe II 5018 (16), Fe II 5169 (9), Fe II 5317 (6), [N II] 5755 (14), [O I] 6300 (21), [O I] 6364 (7). The numbers in parenthesis give the intensity fluxes relative to Hβ (10).

3.2 Near-Infrared Spectrum

A CCD spectrum of the nova (Fig. 5), covering the range 7000–8200 Å, was obtained on November 24.7 with the 1.82 m telescope. Unfortunately, because of the bad sky conditions and the very low location of the nova in the sky, photometric calibrations could not be made. In Table 3 we have reported the identifications and relative intensities of the emission lines in an arbitrary scale, assigning intensity 15 to the [O II] blend 7319–30. The spectrum confirms that the nova, at the end of November, was approaching the nebular stage. The strengthening of the forbidden line of O II, contemporary to the flash of [N II] 5755, is very significant, as well as the presence of the blends of O I, mult. 1, 20, 34, 55, 64, typical of the "Orion phase."

The He I lines at 6678 and 7065 were just emerging from the continuum, but still very weak.

3.3 The Nebular Spectrum

The material available for the study of the nebular spectrum of the nova is listed in Table 1.

The first CCD spectrum of the nova, after the period of seasonal invisibility, was taken at Ekar, with the 1.82 m telescope, on March 21 nearly six months after maximum. The spectrum, covering the range from 4000 to 5000 Å, was sufficient to show that the nova had already attained the nebular phase, displaying strong forbidden lines of [O III] at λ 4959–5007 and λ 4363 Å. This fact was not surprising, because the last spectra taken in November gave already clear indications that the star was approaching the nebular phase. The passage to this stage very likely occurred in the following weeks, in December or in early January.

About two weeks later, since the Asiago sky was cloudy, some CCD spectra were kindly provided at our request, from April 4 to 6, by Marziani (1990) at La Silla. A week later, on April 13, it was possible to secure at Asiago, with the 1.82 m telescope, a set of CCD spectra, covering the range from 3750 to 7800. Other CCD spectra were obtained from May to July 1990. All these spectra were duly calibrated with the spectrophotometric standard Kopff 27 and reduced as indicated above.

Table 4 lists the observed wavelengths of the emission lines, their identification and the intensities on April 5–13,

TABLE 2. Identification and intensity of the emission lines in the prenebular stage.

Obs	Lab	Ident.	Mult.	Oct 5	Oct 6	Nov 8	Notes
				F(λ) / F(Hβ)*			
3769	3759-3761	TiII	13		0.20	--	1
	3770.6	H11	2				
3839	3835.4	H9	2		0.12	--	
3903	3889.1	H8	2		0.08:	--	2
	3906.0	FeII	173				
3937.0	3933.7	CaII	1		0.11	0.07	3
	3935.9	FeII	173				
3927.8	*(- 678 km s^{-1})*						
3917.8	*(-1440)*						
3973.5	3968.5	CaII	1		0.24	0.30	
	3970.1	Hε	1				
3952.5	*(-1330)*	*3947.2*	*(- 1730)*				
4068.0	4064.8	FeII	39		0.03	0.03	
	4066.3	FeII	214				
4110.0	4101.7	Hδ	1		0.33	0.48	4
4093.5	*(- 600)*						
4083.0	*(-1367)*	*4078.0*	*(-1733)*				
4177	4173.5	FeII	27		0.25	0.17	5
	4178.9	FeII	28				
4156.8	*(-1450)*						
4237.5	4233.2	FeII	27		0.27	0.18	
4214.0	*(-1360)*						
4302.0	4303.2	FeII	27		0.14	0.05	
4293.0	*(- 711)*						
4282.0	*(-1478)*						
4352.0	4340.5	Hγ	1		0.57	0.77	6
	4351.8	FeII	27				
4333.5	*(- 642)*						
4321.5	*(-1471)*	*4315.8*	*(-1865)*				
4404.5	4399.8	TiII	51		0.04		7
4416.5	4416.8	FeII	27		0.10	0.16	
4471.5	4471.5	HeI	14		0.11	0.13	8
	4472.9	FeII	37				
4516.5	4515.5	FeII	37		0.21	0.20	
	4520.2	FeII	37				
4552.5	4549.2	FeII	186		0.15	0.15	
	4549.5	FeII	38				
4587.5	4583.8	FeII	38		0.16	0.11	
4636-	4635.3	FeII	186		0.13	0.33	9
-4655	4636.1	NII	5				
	4639.9	NIII	2				
	4649.1	OII	1				
	4650.2	CIII	1				
	4666.6	FeII	37				

* F(Hβ) : Erg $cm^{-2}s^{-1}10^{-11}$x 2.27 (Oct 5); 1.83 (Oct 6); 1.22 (Nov 8).

TABLE 2. (continued)

Obs	Lab	Ident.	Mult.	Oct 5	Oct 6	Nov 8	Notes
				F(λ) / F(Hβ) *			
4863.5	4861.3	Hβ	1	1.00	1.00	1.00	
4849.5	*(- 728)*	*4846.3*	*(- 925)*				
4837.6	*(-1470)*	*4831.7*	*(-1827)*				
4926.4	4923.9	FeII	42	0.49	0.49	0.53	
4912.2	*(-713)*	*4906.5*	*(-1070)*				
4900.0	*(-1456)*	*4894.0*	*(-1790)*				
5020.5	5018.4	FeII	42	0.70	0.74		
5006.5	*(- 710)*						
4993.5	*(-1490)*						
5171.5	5169.0	FeII	42	0.62	0.66		
5156.5	*(- 725)*						
5143.5	*(-1480)*						
5237.0	5234.6	FeII	49	0.13	0.13		
5278.5	5276.0	FeII	49	0.21	0.21		
5319.5	5316.7	FeII	48,49	0.28	0.28		
5365.5	5362.9	FeII	48	--	0.14		
5422.5	5425.3	FeII	49	0.05	--		
5532.0	5529.9	FeII	224	0.09	--		
5579.0	5577.4	[OI]	3F	0.06	--		
5680-	5679.6	NII	3	0.24	0.27		10
- 5755	5750.4	OI	40				
	5754.8	[NII]	3F				
5825.0	5823.2	FeII	164	0.02	0.04		
5894.5	5893.0	NaI	1	0.28:	0.27		11
5877.0	*(- 815)*						
5861.0	*(-1630)*						
5947.0	5937.7	NII	28	0.11	0.13		12
5993.5	5991.4	FeII	46	0.07	0.09		
6089.0	6084.1	FeII	46	0.07	0.05		
6106.5	6103.5	FeII	200				
6152.4	6149.2	FeII	74	0.34	0.32		13
6169.5	6167.8	NII	36,60				
6247.5	6247.6	FeII	74	0.30	0.30		
6302.5	6300.2	[OI]	1F	0.26	0.33		14
6365.0	6363.9	[OI]	1F	0.14	0.13		14
6463.5	6456.3	FeII	74	0.21	0.26		15
6566.1	6562.8	Hα	1	5.46	6.26		
6547	*(- 722)*						
6530	*(-1500)*						

* F(Hβ): Erg $cm^{-2}s^{-1}10^{-11}$x 2.27 (Oct 5); 1.83 (Oct 6); 1.22 (Nov 8).

Notes to TABLE 2

(1) This line appears surprisingly stronger than assumed for H11. Possibly, the principal contributor is Ti II. Later, with increasing degree of excitation, the line weakens and disappears.
(2) Blend; irregular profile.
(3) Double peaked profile.
(4) Very likely Hδ is blent with some other minor contributors (Fe II, mult. 21, 28?).
(5) The radial velocity has been computed assuming 4176.2 as the mean wavelength of the blend of the two Fe II lines.
(6) This line, rather wide, has a peak at 4352 possibly due to blend of Hγ 4340.5 with Fe II 4351.8. We have attributed weight 3 to Hγ and weight 1 to Fe II, deriving for the central wavelength of the blend the value λ 4342.81. Later on, in November, the line appears somewhat distorted towards the red.
(7) These two emission lines are partly superposed. On November 8, however, the Ti II line is barely perceptible.
(8) The presence He I 4471.5 in November is still doubtful.
(9) While in October the principal contributor was Fe II, nearly one month later, the wide blend of N II and O II, extended from about 4630 to 4660, has become predominant. Very likely N III is also contributing to the blend, gaining strength after November 8.
(10) Wide blend of N II mult. 3 and possible also of [N II], with maxima at λ 5675 and 5754 Å.
(11) The bright Na I city lights have been subtracted, but the operation has somewhat altered the original profile of the stellar D_1 and D_2 lines. The fluxes reported in the table give therefore an indicative value.
(12) Wide blend of N II mult. 28.
(13) Very likely the principal contributor is Fe II. However, the lines are so mingled that it is difficult to separate one from the other. Later, in November, also the N II line 6167.8 contributes to the blend.
(14) The night sky component has been previously subtracted.
(15) Blend of several Fe II lines. The principal contributor is Fe II, mult. 74 at 6456 Å.

May 8, and July 13, relative to Hβ. The Notes to the Table give some comments about the presence of blends and doubtful identifications.

The spectra taken on April 4–13 indicate an increasing degree of ionization, as shown by the presence of the lines of [Fe VI], [Fe VII], [A III], [A IV], [A V], [K IV], [Ca V], and possibly also [Fe X 6374], blended with [O I 6364]. He II lines were also observed: 4686 with moderate intensity, the others much weaker. He I was represented by the following lines: 4471, 5048, 5876, 6678, 7065, all relatively weak. The strongest components in the spectra were Hα and Hβ, the nebular lines of [O III] at λ 4959–5007 and [Ne III] at λ 3869–3968, and the auroral lines of [O III] λ 4363 and [N II] 5755. Most of them displayed saddle type or castellated profiles.

The spectrum of May 8 (Fig. 6) maintained substantially the same structure. The absolute intensities of all the emission lines, were less than in April 4–13, because of the de-

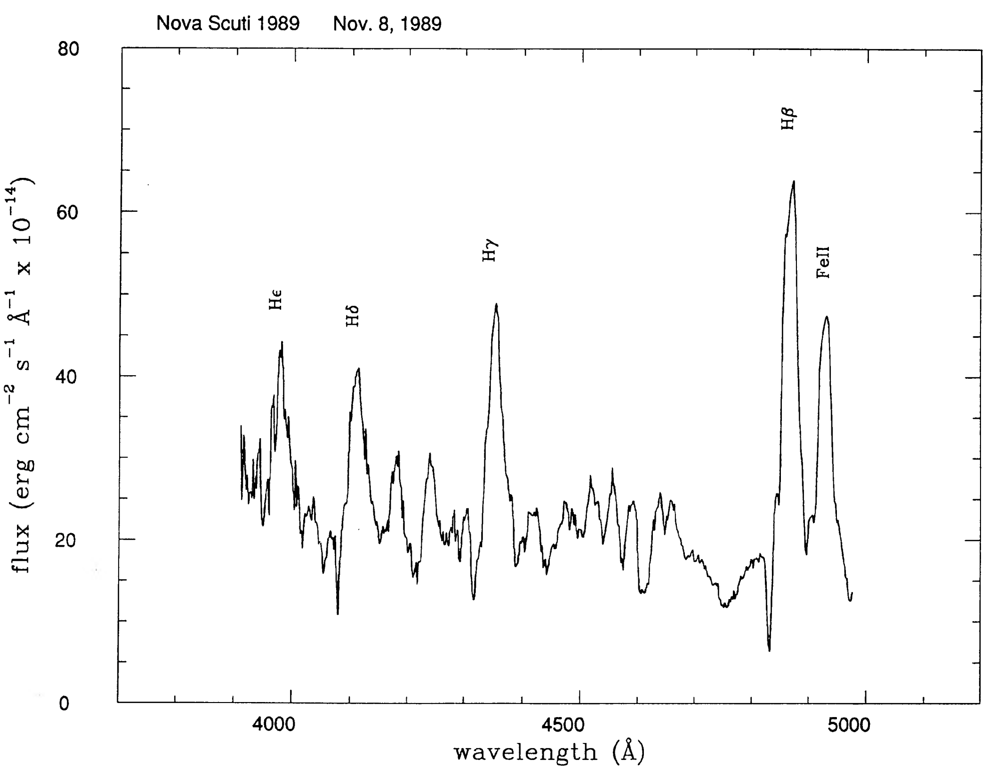

FIG. 3. CCD spectrum near the transition phase.

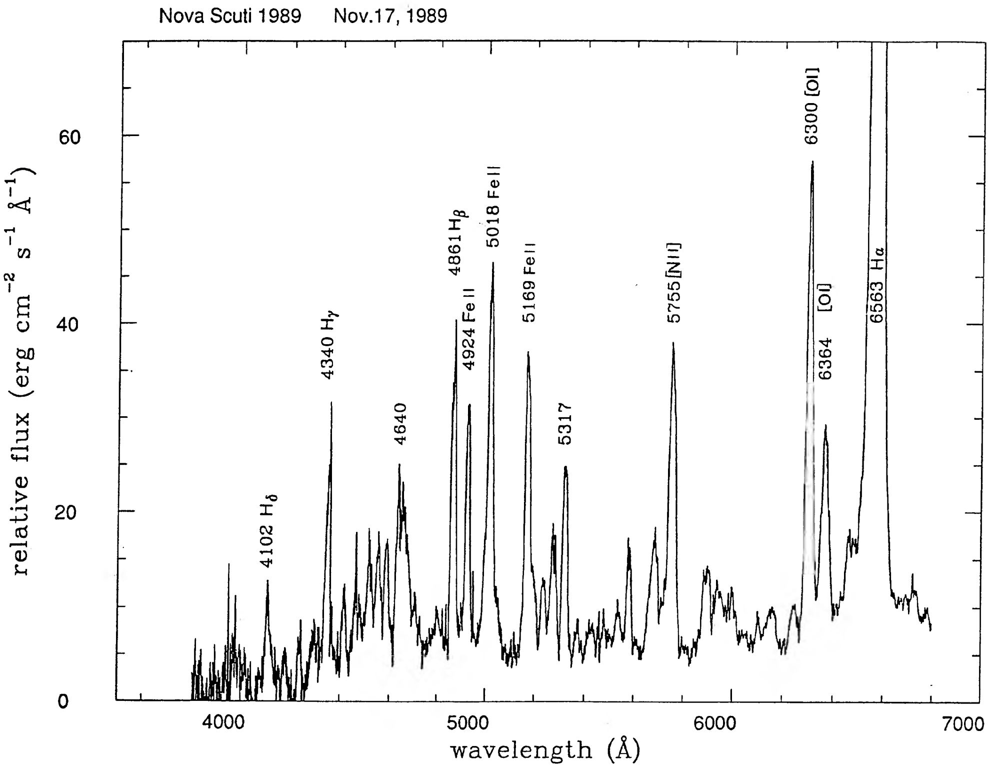

FIG. 4. Intensity spectrum of Nova V443 Sct in the transition phase. Zero point and scale are arbitrary.

creasing flux of radiation from the nova remnant and the continuing expansion of the nebular envelope; while, relatively to Hβ, the forbidden lines of higher I.P. strengthened. This effect was still more apparent in the last spectra, taken on July 8 and 13, after the nova had declined to about 14.7. The strongest lines about 300 days after maximum, were, besides Hα (blended with the [N II] doublet at 6548 and 6484) the forbidden lines of O III, Ne III, N II, and O II. Many lines of [Fe VI] and [Fe VII] were also present.

The average expansion velocity of the ejecta, derived from the FWHM of Hβ, [O III] 5007, [O III] 4959, [N II] 5755 and Hα, was 1500 ± 110 km s^{-1}, in April and in May. In July the expansion velocity was somewhat less: 1320 ± 90 km s^{-1}, excluding, however, Hα from the mean, because this line was clearly blended with [N II] lines, as shown by the increase of its width.

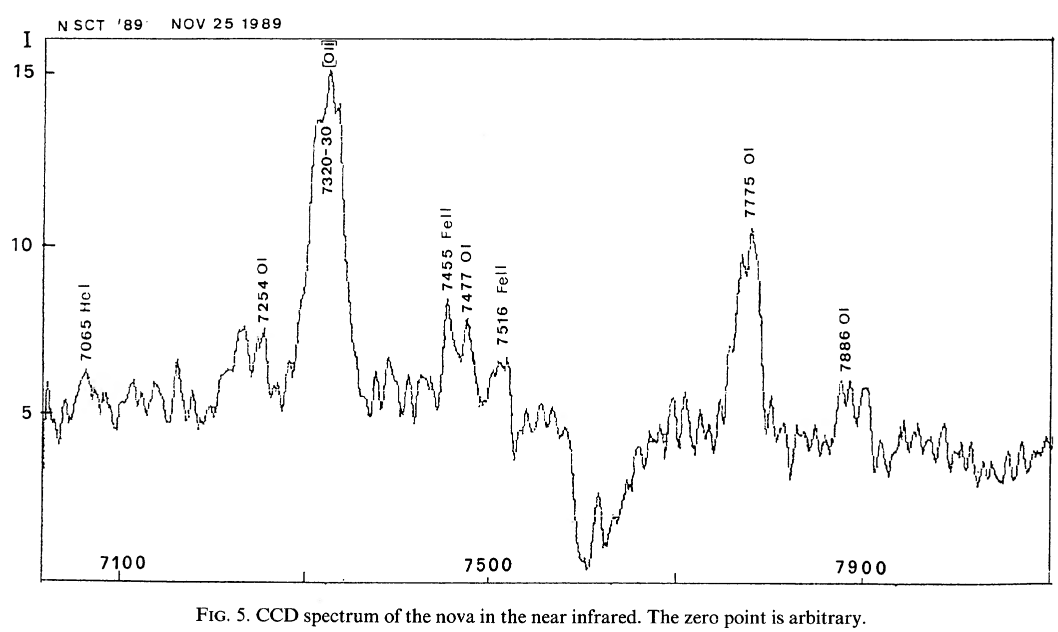

FIG. 5. CCD spectrum of the nova in the near infrared. The zero point is arbitrary.

TABLE 3. Identification and relative intensity of emission lines in the near infrared (25 November 1989).

Obs.	Lab.	Ident.	Mult.	Int.	Notes
6688:	6678.1	HeI	46	1.0	1
6736:	6726.4	OI	2	1.0	2
7063	7065.2	HeI	10	1.3	1
7232	7222.4	FeII	73	2.4	
7254	7254.3	OI	20	2.3	
7326	7319.5 7330.0	[OII]	2F	10.0	3
7455- -7475	7449.3 7462.4 7477.3	FeII " OI	73 73 55	3.3 2.6	4
7518	7515.9	FeII	73	1.4	
7775	7772.0 7774.2 7775.4	OI	1	5.4	5
7890	7886.3	OI	64	1.4	6
8221-33	8227.4	OI	34	1.5	

* The zero-point in the column of intensities has been fixed arbitrarely , attributing intens.10 to the [OII] doublet 7320-7330. The intensities of the other lines are related to this zero-point.

Notes to TABLE 3

(1) Barely registered over the noise. Possibly due to He I.
(2) Dubious identification. Barely visible.
(3) This blend of the forbidden O II at 7319–30 is outstanding in the near infrared spectrum.
(4) Partial blend of Fe II and O I with peaks at 7455.5 and 7475.7. O I contributes to the blend with all the components of mult. 55.
(5) Blend of the O I triplet mult. 1.
(6) Blend with peaks at 7878, 7888, 7904. One possible contributor could be O I 7886.

4. DISCUSSION

4.1 Reddening and Distance

In order to discuss some of the data reported in Tables 1–4 it is necessary to estimate, at least approximately, the reddening of the nova due to interstellar absorption. The color excess in the present case has been tentatively determined: (a) By comparing the observed mean color index of the nova ($B-V=+0.35$) with the corresponding $(B-V)_0$ indices, at about the same phase, of unreddened galactic novae having light curves alike to that of N Sct 1989. Their mean color, 1–1.5 mag below maximum, is not less than 0.05 (van den Bergh & Younger 1987), so that the color excess of this nova can hardly be higher than 0.30 and possibly is less than this.

The reddening could also been obtained (Whitney & Clayton 1989) from the ratio of the flux intensities of the He I lines 5876/4471. In the present case the observed mean ratio of three determinations (Table 4) is: 3.6 ± 0.7, somewhat higher than the theoretical value (2.8). Since the ratio 5876/4471 seems to be free from radiative transfer effects (Ferland 1977), the difference 0.8 should be attributed to interstellar absorption. The E_{B-V} excess is therefore consistent with the value previously obtained from the color indices.

From the rate of decline ($d_2 = 0.09$ mag d^{-1}) it is possible to derive the absolute magnitude of the nova at maximum: $M_v = -7.8$ using the MMRD relation (Capaccioli *et al.* 1989). Adopting, moreover, $V = 7.5$ for the corresponding apparent magnitude, the distance of the nova

TABLE 4. The nebular phase: emission lines from 3750 to 7800 Å.

Obs	Lab	Ident.	Mult.	Apr 5-13	May 8	Jul 13	Notes
				F(λ)/ F(Hβ)*			
3758	3756.1	HeI	66	0.09	-	-	
3876	3868.8	[NeIII]	1F	0.57	0.79	0.92	
3971	3967.5	[NeIII]	1F	0.25	0.32	0.39	1
	3970.1	Hε	1				
4071	4071.5	[FeV]	1F	-	-	0.10	
4100	4101.7	Hδ	1	0.37	0.37	0.26	
4139	4136.4	[FeV]	1F	-	-	0.11	
4192	4199.8	HeII	3	-	-	-	
4275	4276.8	[FeII]	21F	-	-	-	
4343	4340.5	Hγ	1	1.78	0.25	0.30	2
4362	4363.2	[OIII]	3F		1.70	1.82	
4417	4415.4	[FeII]	6F	0.04	0.05	0.07	3
	4416.0	OII	5				
4473	4471.5	HeI	14	0.06	0.09	0.07	
4516	4510.9	[KIV]	3	0.04	0.05	0.11	4
	4514.9	NIII	3				
4641	4641.2	NIII	2	0.51	0.50	0.52	5
4687	4685.7	HeII	1	0.20	0.21	0.23	
4702	4699.0	[FeVII]	2F	-	-	-	
4861	4861.3	Hβ	1	1.00	1.00	1.00	6
4958	4958.9	[OIII]	1F	1.81	2.79	4.57	7
5007	5006.8	[OIII]	1F	6.37	8.32	14.08	7
5048	5047.7	HeI	47	0.15	0.21	0.14	
5165	5158.3	[FeVII]	2F	0.16	0.17	0.16	
	5177.0	[FeVI]	2F				
5274	5276.1	[FeVII]	2F	0.13	0.14	0.19	
	5279.2	[FeVI]	1F				

* F(Hβ):114 x 10^{-14}erg $cm^{-2}s^{-1}$(Apr 5-13); 91.6 (May 8); 38.9 (Jul 13)

TABLE 4. (continued)

Obs	Lab	Ident.	Mult.	Apr 5-13	May 8	JUL 13	Notes
				F( )/ F(Hβ)			
5302	5309	[CaV]	1F	-	0.05	0.06	8
5410	5411.5	HeII	2	0.03	0.04	-	3
5535	5534.6	[AX]	1F	0.03	0.04	-	3
5677	5678.0	[FeVI]	1F	0.17	0.15	0.13	
5713	5721.1	[FeVII]	1F	-	-	0.12	9
5757	5754.8	[NII]	3F	1.43	1.58	1.92	10
5874	5875.6	HeI	11	0.25	0.26	0.27	
5940	5938	NII	28	0.05	0.04	0.05	11
6086	6085.5 6085.9	[FeVII] [CaV]	1F 1F	0.13	0.22	0.42	12
6300	6300.2	[OI]	1F	0.39	0.34	0.33	
6365	6363.9 6374.5	[OI] [FeX]	1F 1F	0.28	0.25	0.28	13
6483	6478.7	NIII	14	0.06	0.09	0.08	
	6548.1	[NII]	1	-	0.30	0.58	
6561	6562.8	Hα	1	8.76	6.93	7.35	14
	6583.6	[NII]	1F	-	0.86	1.68	
6675	6678.2	HeI	46	0.11	0.11	0.13	
7002	7006.3	[AV]	1F	0.04	0.03	0.06	
7065	7065.1	HeI	10	0.24	0.22	0.21	
7138	7135.8	[AIII]	1F	0.21	0.24	0.41	
7234	7236.8	[AIV]	2F	0.07	0.04	0.07	
7323	7319-30	[OII]	2F	1.68	1.85	2.36	
7590	7592.7	HeII	6	-	0.02		
7766	7751.0 7773.9	[AIII] OI	1F 1	0.13	0.11	0.15	15

* F(Hβ):114×10^{-14} erg $cm^{-2} s^{-1}$ (Apr 5-13); 91.6 (May 8); 38.9 (Jul 13).

Notes to Table 4

(1) Blend of [Ne III] with Hϵ. Very likely [Ne III] is the principal contributor.
(2) Hγ and [O III] 4363 are partly blended. The deconvolution of the profile, through the best fitting with Gaussian curves, has been possible only in the spectra of May and July.
(3) Very weak; the identification is doubtful.
(4) Possibly blend of N III with [K IV].
(5) Partly superposed to He II 4686.
(6) The profile of Hβ is very asymmetric with several peaks. The strongest is observed in the red side, at λ 4868.
(7) Both the nebular lines of [O III] 4959 and 5007 display a complex double peaked profile. The peaks, of nearly the same strength, have radial velocities -174 km s^{-1} and $+488$ km s^{-1} relative to the central dip. The intensity is rapidly increasing, from April to July.
(8) A weak line at about λ 5302 is certainly present. Excluding a very unlikely identification with [Fe XIV], the only possible contributor is [Ca V].
(9) This weak line was not recorded in April and May, but became clearly visible in July.
(10) The complex profile, with the strongest peak in the red side, is alike to that of Hβ.
(11) Weak blend of N II mult. 28.
(12) Very likely [Fe VII] is the principal contributor. The line is double peaked, like the other [Fe VII] lines in the spectrum. The radial velocities of the two peaks are: -370 and $+518$ km s^{-1}.
(13) The [O I] line at 6364, which appears stronger than expected, possibly is blent with [Fe X] 6373.
(14) The profile is alike to that of Hβ; the highest peak is at λ 6572. The intensities relative to Hβ of the [N II] nebular lines, deeply imbedded in Hα, have been increasing from April to July. A deconvolution, although difficult (Iijima 1991), has led to the data reported in the table.
(15) The principal contributor is [A III] 7751.0; the O I line at 7773.9 could also enter significantly in the blend.

would be: $D \sim 7.6$ kpc; a rather dubious value, however, which depends too strongly on the precedent assumptions.

4.2 Early Decline

The spectra obtained two or three weeks after maximum (Table 1) do not present particular anomalies, besides a steep Balmer decrement on which we shall return below. The bright lines are emitted, mostly through the normal recombination process, from atoms of low I.P., ionized by the radiations coming from the underneath photospheric layers ejected during the outburst. The absence in the spectra of the lines of He I and other atoms with I.P. > 20 eV indicates that the photospheric temperature T_0 is still $\leqslant 10^4$ K. The occurring of some N II lines at this phase might, however, suggest a limitate degree of collisional excitation in the expanding envelopes.

Collisionally excited [O I] lines at 5577 and 6300–6364 are recorded, although weak, in these spectra. Their presence, and that of other neutral atoms (O I, Na I) may denote the formation of an extended neutral region outer than the ionized one (Mazeh *et al.* 1985).

At the beginning of the transition stage, the expanding layers reach a higher degree of ionization, as shown by the presence of relatively strong lines of N II 5676, [N II] 5755, [O II] 7319–30, and the contemporary marginal appearance

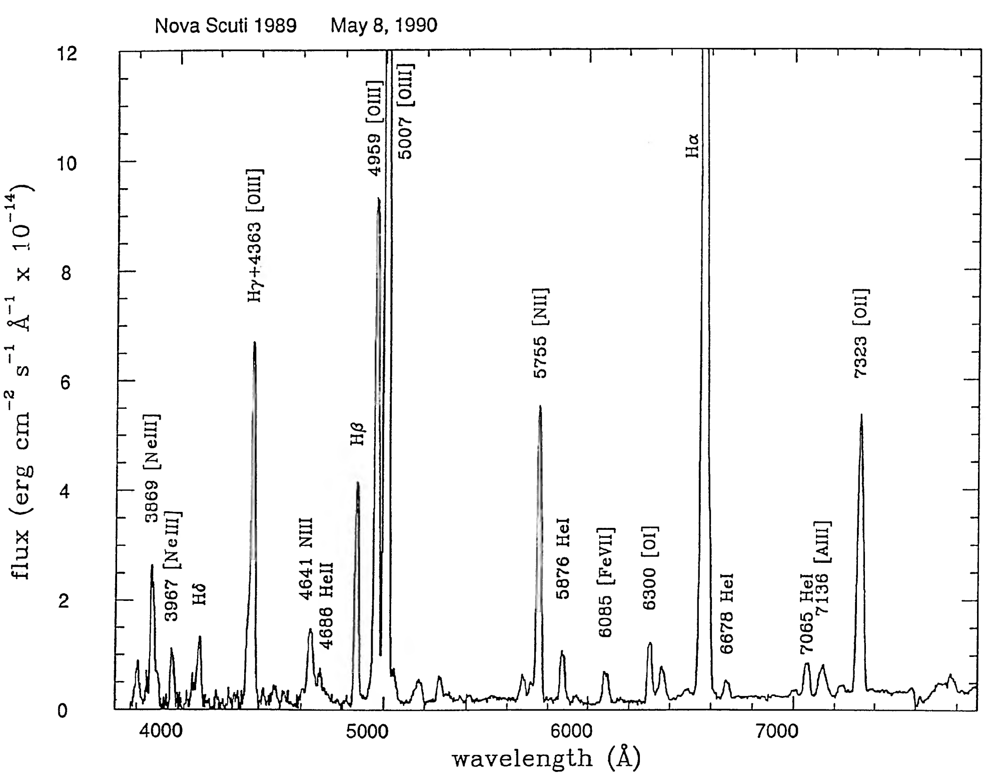

FIG. 6. The nebular spectrum of the nova obtained with the CCD about 8 months after maximum.

of He I. The temperature of the contracting photosphere very likely has reached at this stage about 35 000 K (Martin 1989). The nova is following the pattern outlined in the TNR model (Bath *et al.* 1989).

4.3 Balmer Decrement

A steep Balmer decrement, although not rare in galactic novae (Gallagher 1978; Whitney & Clayton 1989) is, however, somewhat anomalous. In the early decline the ratio $H\alpha/H\beta$, corrected for interstellar extinction, was 4.1, still too high compared with the theoretical value (2.8); but in the course of the nebular phase (May–July 1990) it raised to 5.2 ± 0.8 and this excess by no means can be attributed to reddening. Since the intensities of the Balmer lines other than $H\alpha$, after having removed any possible contamination from close lines, are in fair agreement with those calculated, the steep $H\alpha/H\beta$ ratio should be attributed to an excess of intensity of $H\alpha$, due to optical depth effects (e.g., $H\beta$ self-absorption with partial reconversion to $H\alpha$), and possibly also to collisional excitation from the ground state (Ferland 1987; Gallagher 1978).

4.4 Temperatures

From the ratio of the intensities of the nebular to the auroral lines of [O III]: $J(4959+5007)/J\,4363$ it is possible to obtain either the electron density or the electron temperature T_e. Assuming $T_e \sim 2\times10^4$ K, the electron density becomes: $N_e = 2\times10^6$ in May, decreasing to 1.2×10^6 in July. This result does not substantially change by using, in order to derive both T_e and N_e, the ratio of the nebular to the auroral lines of [N II], together with that of [O III], after having tentatively determined the intensities of the [N II] lines 6548 and 6583, still rather weak and deeply blended with $H\alpha$.

The presence of emission lines of He I, He II, [O III], [Ne III], and [Fe VII] in the nebular spectra, from April to July 1990, (Table 4) is sufficient to indicate that the central source of ionization has reached a very high temperature.

A quantitative determination has been made by using the relation (Osterbrock 1974),

$$\frac{J(4686)}{J(5876)} = \frac{5876\alpha(4686)\alpha_B(\mathrm{He}_0)\int_{4\nu\mathrm{H}}^{\infty} B\nu(T)/h\nu\, d\nu}{4686\alpha(5876)\alpha_B(\mathrm{He}+)\int_{1.81}^{4\nu\mathrm{H}} \frac{B\nu}{\nu\mathrm{H}}(T)/h\nu\, d\nu},$$

under the assumption that most of the photons with energy above 24.6 and 54.4 eV should be absorbed, respectively, by He_0 and $\mathrm{He}+$ and that the electron temperature be $\sim 2\times10^4$ K. From the observed mean value of the ratio $J4686/J5876$ (corrected for extinction) a mean effective temperature $T_0 \sim 183\,000$ K has been derived for the period April–July 1990.

This very likely represents a lower limit of the temperature of the central remnant, which would rise to about 3.5×10^5 K if the suspected presence of [Fe X] 6374 and [A X] 5535 were confirmed (Ferland 1978; Krautter & Williams, 1989). It is clear, moreover, that on July 1990 the nova was far from reaching its minimum and that the central remnant was still in a phase of contraction at increasing temperature. Spectra of Nova Sct 1989 possibly taken in 1991 or 1992, during the final decline, would be of the highest interest.

TABLE 5. Helium abundance.

Date 1990	N(He+)/N(Hβ)	N(He++)/N(H)	(He)/N(H)	N(He+)/N(Hα)	N(He++)/N(H)	N(He)/N(H)
4471/Hβ						
Apr 5-13	0.154	0.020	0.174	0.082	0.010	0.092
May 9	0.222	0.021	0.243	0.120	0.011	0.131
Jul 13	0.176	0.022	0.198	0.090	0.011	0.101
5876/Hβ						
Apr 5-13	0.180	0.020	0.200	0.095	0.010	0.105
May 9	0.187	0.021	0.208	0.101	0.011	0.112
Jul 13	0.194	0.022	0.216	0.099	0.011	0.110
6678/Hβ						
Apr 5-13	0.232	0.020	0.252	0.122	0.010	0.132
May 9	0.234	0.021	0.255	0.135	0.011	0.146
Jul 13	0.298	0.022	0.320	0.152	0.011	0.163

With 6678: N(He)/N(H)= 0.229 ± 0.044 N(He)/N(H)= 0.121 ± 0.023

Without 6678: N(He)/N(H)= 0.206 ± 0.023 N(He)/N(H)= 0.109 ± 0.013

4.5 Helium Abundance

The He abundance, relative to H, has been tentatively determined by using the relation (Ferland 1978),

$$\frac{N(\mathrm{He})}{N(\mathrm{H})}=\frac{J(\mathrm{He\,I})\alpha(\mathrm{H}\beta)\nu(\mathrm{H}\beta)}{J(\mathrm{H}\beta)\alpha(\mathrm{He\,I})\nu(\mathrm{He\,I})}+\frac{J(\mathrm{He\,II})\alpha(\mathrm{H}\beta)\nu(\mathrm{H}\beta)}{J(\mathrm{H}\beta)\alpha(\mathrm{He\,II})\nu(\mathrm{He\,II})}.$$

Since it is possible that Hβ might suffer of self-absorption and be partially converted in Hα, following the criterion adopted by Whitney & Clayton (1989) we have used the ratio of the intensities of the He lines to Hβ (corrected of reddening) in order to have an upper limit of the helium to hydrogen abundance, and the ratio to Hα for a lower limit.

Table 5 gives the values of $N(\mathrm{He})/N(\mathrm{H})$ calculated on April, May, and July 1990, respectively, from the intensity ratio to Hβ of: He 4471, 5876, 6678, and He II 4686 (columns 2–4); and to Hα (columns 5–7).

It can be remarked from Table 5 that the abundances of He obtained from the ratio of He I 6678 to Hβ are always higher than those calculated from He I 4471 and 5876 and moreover that He I 6678 shows a tendency to increase with time when compared with He II 4686. Since only the forbidden lines have a similar behavior, it appears likely that the He I line 6678 might be blent with some forbidden line, e.g., [Ni II] 6678 or [Ti II] 6671.

The last two lines in Table 5 give the total mean values of $N(\mathrm{He})/N(\mathrm{H})$ according that He 6678 is included or not in the mean. It can be seen that the He abundance cannot be higher than 0.23 neither lower than 0.11, relative to H. However, considering that the He lines in the spectra of this nova are somewhat weaker than in most of the other novae at about the same phase, we rather incline to assume the second value (0.11) as the most likely; the helium abundance in Nova Scuti 1989 would be in this case comparable with the solar abundance (0.08).

On the other hand, as remarked by Peimbert & Torres-Peimbert (1987) and by Clegg (1987), in dense nebulae (as could be considered the nova ejecta) a significant part of the intensity of the He emission lines could be due to collisional excitation. This effect will be discussed in a forthcoming paper.

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