SPECTROSCOPIC OBSERVATIONS OF NOVA CEPHEI 1971

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Abstract. Spectroscopic observations of Nova Cep 1971 in the visual and infrared regions were carried out at Asiago from July to December 1971. The spectra were characterized at first by the presence of wide emission bands of moderate excitation (H, O I, N I, Fe II) accompanied by two absorption systems with mean radial velocity -1300 km s^{-1} and -2200 km s^{-1}. The velocity was increasing with time. The absorption spectrum disappeared in September and soon the nova entered the nebular stage. The He I flash was observed in mid-September. In the following months the degree of excitation was steadily increasing. The nebular [O III] lines became outstanding, even stronger than Hα and the spectrum was characterized by forbidden and permitted lines of relatively high ionization potential (O II, O III, N II, N III, He II).

The profiles of the emission bands were complex from the beginning, with a strong central peak. Later, most of the bands split into two separate components, with radial velocities ± 1360 km s^{-1}.

The light curve was that of a relatively fast nova. The minimum, $B \sim 17.5$, was attained in the first half of 1973.

Nova Cephei 1971 (α 22^{h}2^{m}47^s; δ +53°15′39″; 1950.0) was discovered by Kuwano (1971) on July 10 as a star of visual magnitude 8. From July 13 to December 11, slit spectrograms in the blue-red and infrared region were obtained at Asiago at the cassegrain focus of the 122 cm telescope with the one-prism spectrograph in the following combinations:

Camera AVI (60 Å mm^{-1} at Hγ) with Carnegie-RCA image tube S 20.

Camera AVII (365 Å mm^{-1} at 8000 Å) with Carnegie-RCA image tube S 1.

Thirty-three spectra were obtained with the first combination; twelve infrared spectra with the second, all being evenly distributed in the interval covered by the observations.

During the same time, B and V observations were made with the 67 cm Schmidt telescope on 103a-O plates + GG13 and 103a-D + GG14. The observations were continued in the following years.

The reduction of the spectroscopic material was made at Asiago with the Hilger and Watts microphotometer and the Hilger measuring machine, following the usual techniques.

1. The Light Curve

B and V light curves of this nova are reproduced in Figure 1. Dots and full triangles indicate Asiago observations; circles and open triangles observations of other authors (Huruhata, 1971; Tsessevich, 1971; Alksnis and Dunzans, 1972; Kohoutek and Klawitter, 1973; Thomas *et al.*, 1973; Aikman *et al.*, 1973). B and V magnitudes were derived from visual estimates assuming for the comparison stars the magnitudes reported in Table II by Kohoutek and Klawitter (1973).

The maximum of about $7^m.5$ ($B-V \approx 0$) was probably attained on July 6. The early decline went from July 6 to 17; the transition phase occurred from July 22 to August 15,

Sherwood and Plaut (eds.), Variable Stars and Stellar Evolution, 347–354.

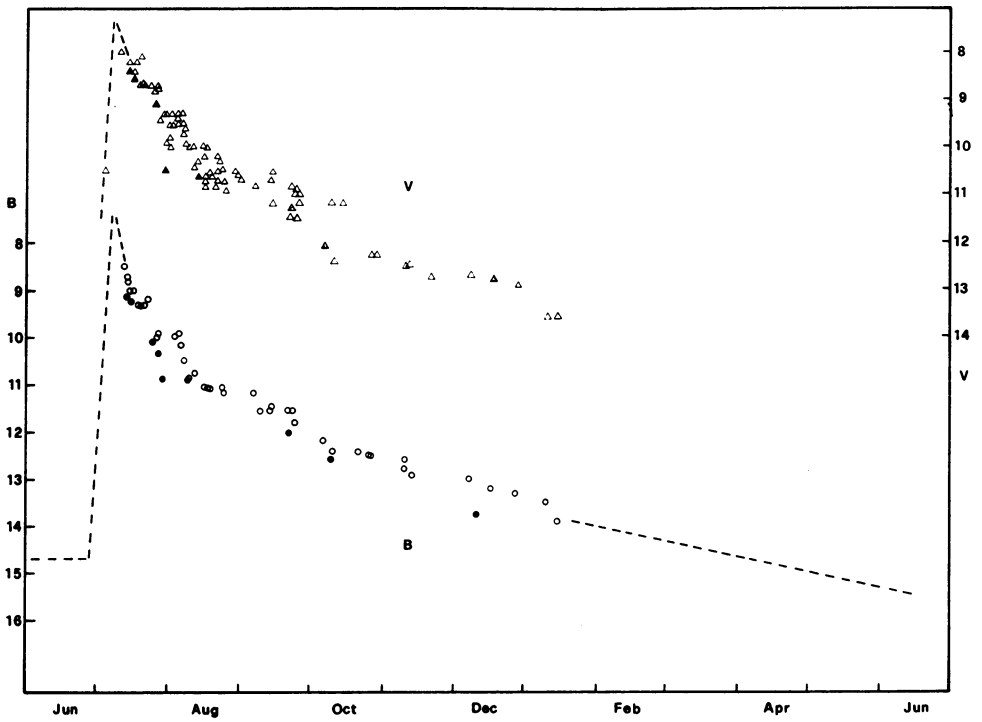

Fig. 1. *B* and *V* light curves of Nova Cephei 1971. Full dots and triangles are Asiago observations. Circles and empty triangles observations by other authors.

followed by the final decline. The minimum was reached, according to Asiago observations, in June 1973 with a *B* magnitude of about 17–17.5. Strong brightness fluctuations were observed during the transition phase. The $B-V$ color index increased from -0.2 to $+0.5$ between July 10 and 18, then slowly declined to $+0.2$ at the end of the year. Of course, the variation mainly depends on the strengthening and disappearance of emission lines.

The prenova magnitude was of the order of 17.2 *B*, with strong oscillations from 16.8 to 18. Recent Asiago observations show the nova at about 17.5–18. Assuming for the minimum the mean value 17.5, the amplitude is 10 mag.

The light curve is that of a relatively fast nova ($t_2 = 16^d$; $t_3 = 28^d$). According to Thomas *et al.* (1973) the absolute magnitude of the nova at maximum, derived by means of McLaughlin's (1960) statistical relations was -8.3. Bahng (1972) gives an absolute magnitude from -7.8 to -8.1. The rate of decline over the first two magnitudes being 0.0125 mag d^{-1}, we obtain (Rosino, 1964) $M_v = -7.5$. Assuming the average value -7.9 as the absolute magnitude at maximum, the intrinsic brightness at minimum is $+2.1$, somewhat brighter than normal for a fast nova. The star should be kept under observation since the prenova light curve seems to indicate the presence of deep eclipses.

https://doi.org/10.1017/S0074180900010470 Published online by Cambridge University Press

2. Spectral Evolution

The spectral evolution of Nova Cephei can be described as follows:

July 14–25. During this period the spectrum of the nova was characterized by the presence of wide emission features bordered by blue-displaced absorptions. Two absorption systems were apparent in the low dispersion spectrograms taken at Asiago: system I (principal) with a mean radial velocity $\bar{V}_1 = -1300 \pm 170$ km s^{-1}; system II (diffuse-enhanced), stronger than the first, having mean radial velocity $\bar{V}_2 = -2100 \pm \pm 250$ km s^{-1}. The presence of the diffuse-enhanced system suggests that the nova was about a week past maximum when the first spectra were taken.

The emission features were broad, their halfwidth corresponding to an expansion velocity $V_e = 830$ km s^{-1} on July 14 and 870 km s^{-1} on July 25. The profiles were complex, with several maxima. The strongest emission lines observed in the blue-red spectrum were: the Balmer lines from Hα to Hδ; Fe II mult. 42 ($\lambda\lambda$ 5169, 5018, 4924 Å), Fe II mult. 49, N II λ 5680 Å, He I λ 5875 Å. In the infrared the strongest features were: the O I blend λ 7772–75 Å, N I λ 8216 Å, O I λ 8446 Å very strong, N I λ 8680–8703 Å and the Paschen lines (P_{10}, P_9, P_8, P_7). The excitation was rather moderate. The following forbidden lines were observed: [O II] λ 7320–30 Å, [O I] λ 6364 Å and λ 6300 Å, [N II] λ 5755 Å weak and some doubtful [Fe II] lines.

July 29–August 11. The absorption lines of systems I and II were still present with about the same intensity. Some lines were hazy, confused and blended together. The following mean velocities were derived:

$$\bar{V}_1 = 1340 \pm 225 \text{ km s}^{-1}$$
$$\bar{V}_2 = 2240 \pm 225 \text{ km s}^{-1}$$

The excitation was slowly increasing. Besides the Balmer and Paschen lines, the following features were becoming prominent: [O I] λ 6364–6300 Å, He I λ 5875 Å, [N II] λ 5755 Å, N II λ 5680 Å and the N II–N III blend at λ 4640 Å. In the infrared the N I and O I emissions at $\lambda\lambda$ 7772–75, 8216, 8446, and 8680–8703 Å were attaining their highest intensities. The profiles of the emission bands were always very peculiar.

August 15–28. The spectra taken during this period, when the nova was passing from the transition to the nebular stage, were characterized by the fading of the absorption components. On August 27 some wide confused absorptions were still present, giving the following mean velocities:

$$\bar{V}_1 = 1550 \pm 260 \text{ km s}^{-1}; \quad \bar{V}_2 = 2535 \pm 290 \text{ km s}^{-1}.$$

The peculiar structure of the emission bands was very remarkable: most of them presented a triple structure with a strong sharp feature in the centre and two symmetrical components at the edges. The expansion velocity from the halfwidth of the emission bands was $V_e = 865$ km s^{-1}. The excitation was rising. [N II] λ 5755 Å was

now outstanding, even stronger than Hβ, while the lines of low excitation (N I, O I, Fe II) were fading. [O II] λ 7220–30 Å was brightening.

September 1–22. On September 12, about two months after maximum, no great differences from the last spectra of August were noticed, except for the He I emission which was much stronger now than in August and the blend [O II] 7320–30 Å which was becoming prominent. The mean expansion velocity, however, was even higher: $V_e = 1360 \pm 300$ km s^{-1}. Some doubtful absorption components with velocities of 2240 and 3360 km s^{-1} were observed. The nebular [O III] band, at λ 5006 Å still weak, had been present since August 28.

A striking change in the spectrum occurred a few days later, between September 12 and 22, when the star entered the nebular stage. The spectra obtained on September 22 were characterized by the presence of strong [O III] emission lines at $\lambda\lambda$ 4363 Å and 4959–5006 Å, this last quite outstanding. The He I flash occurred at the same time, with the sudden strengthening of all He I emission lines at $\lambda\lambda$ 7065, 6678, 5876, 5047, 5018, and 4471 Å. At this stage the nova was about 4 mag. below maximum.

The three emission features $\lambda\lambda$ 5876 Å He I, 5755 Å [N II] and 5680 Å N II were now prominent together with the wide blend λ 4640 Å of N III. He II λ 4686 Å was also present with a very sharp central peak. The infrared spectra were characterized by the strengthening of [O II] λ 7620–30 Å and particularly of He I λ 10830 Å which was extremely strong at the limit of sensitivity of the S1 photocathode. At the same time, all of the emission features of low ionization potential (O I, N I, and Fe II), some of which were very strong in the preceding spectra, weakened or disappeared. The sole exception was O I λ 8446 Å which was still very strong and excited by Lβ.

October-December. The last spectra obtained from October to December 1971, when the nova was 6–7 mag. below maximum, showed a further increase of excitation in the envelope ejected by the nova. With the fading of O I λ 8446 Å, most of the He I emissions also weakened or disappeared. The strongest emission features were: [O III] λ 5006 Å, Hα, [O III] λ 4959 Å, [O III] λ 4363 Å, Hβ, [N II] λ 5755 Å, [O II] λ 7320–30 Å, and N III λ 4640 Å. He I λ 5876 Å, although weakened, was still present as well as N II λ 5680 Å, He II λ 4686 Å was strengthening.

A characteristic feature, common to most of the novae in an advanced stage of spectral evolution, was the splitting into two well-separated components of most of the emission bands. This phenomenon was particularly apparent in the last spectra and was due to the disappearance of the sharp central component and the strengthening of the emission peaks at the edges of the emission bands.

The spectral evolution of Nova Cephei is illustrated in Figures 2 and 3, which reproduce the sequence of the spectra in the blue-red and infrared, from July to November. Tracings of the spectra, showing the complex form of the profiles and the striking changes occurring in the spectra, are reproduced in Figures 4 and 5. Lists of the emission features observed in the spectra, with identifications and relative intensities are given in Tables I–II.

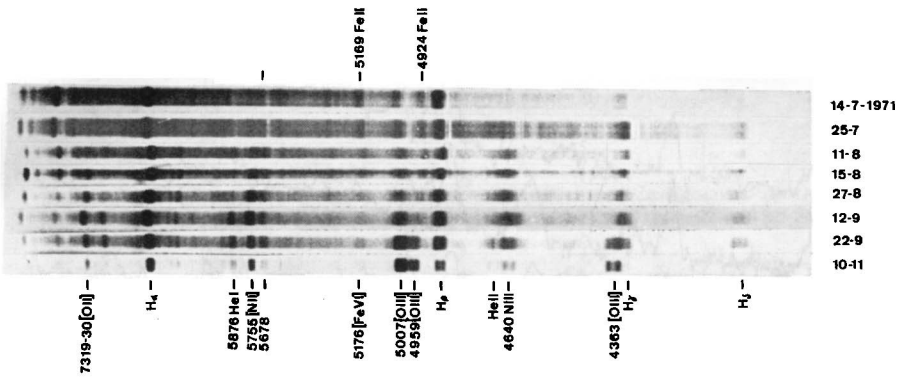

Fig. 2. Evolution of blue-red spectra from July 14 to November 10.

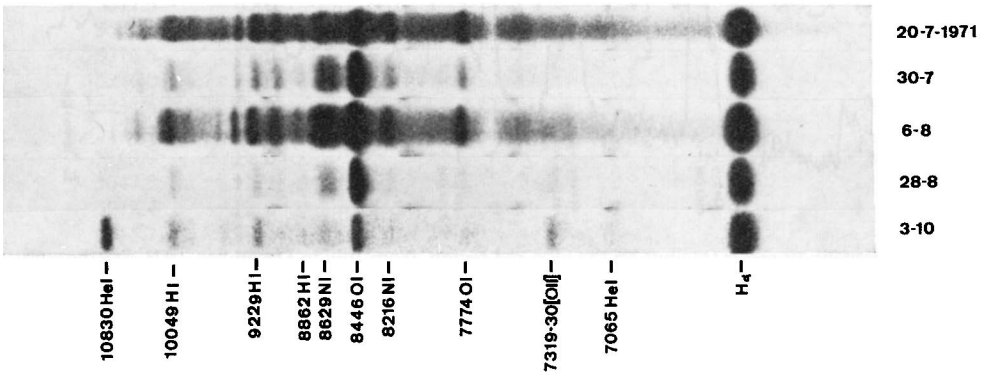

Fig. 3. Evolution of infrared spectra of N Cephei 1971.

In conclusion Nova Cephei 1971 can be considered as a normal fast nova, following a regular pattern of evolution. Although it was not possible to obtain spectra after 1971, it is almost certain, from the comparison with other similar novae observed at Asiago (Ciatti and Rosino, 1974), that the degree of excitation continued to increase during 1972 (and possibly in 1973) with the appearance of forbidden lines of still higher ionization, as for instance Fe VI and Fe VII. The presence of a sharp emission component at the centre of the emission bands during the first months after the outburst strongly suggests that the nova might have been surrounded by a quiescent envelope which was finally thrown off by the layers ejected during the outburst. Quiescent envelopes around novae seem to be a common feature of this class of objects.

Acknowledgement

It is a pleasure to thank A. Bianchini and L. Guzzi for helpful collaboration in the reduction of the spectra.

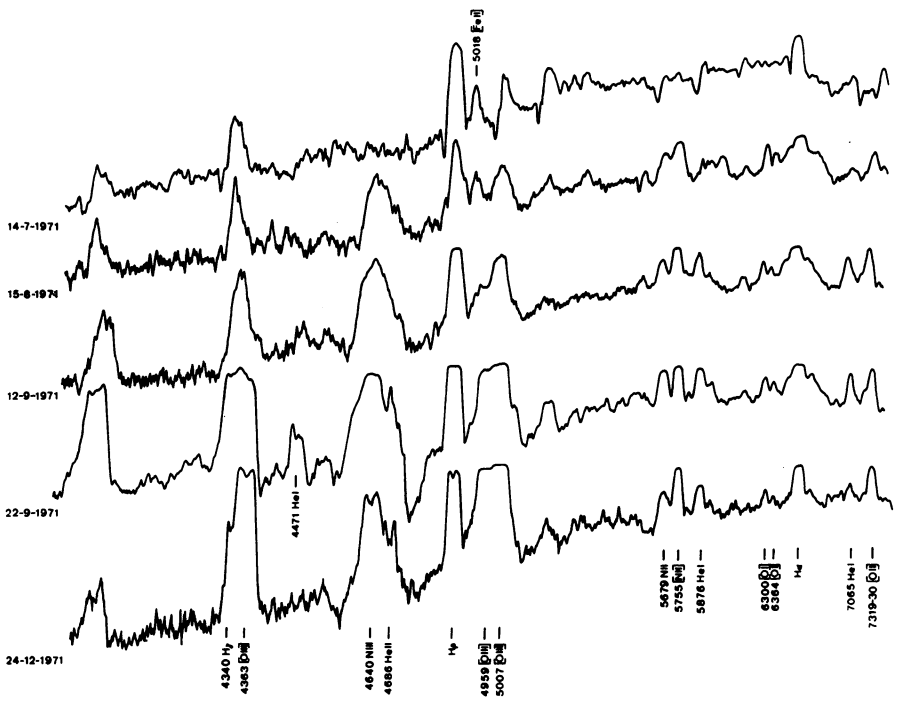

Fig. 4. Microphotometer tracings on the blue-red region, from July to December, 1971. See the complex profile of some emission bands and the neat blue displaced absorptions in the upper spectrum.

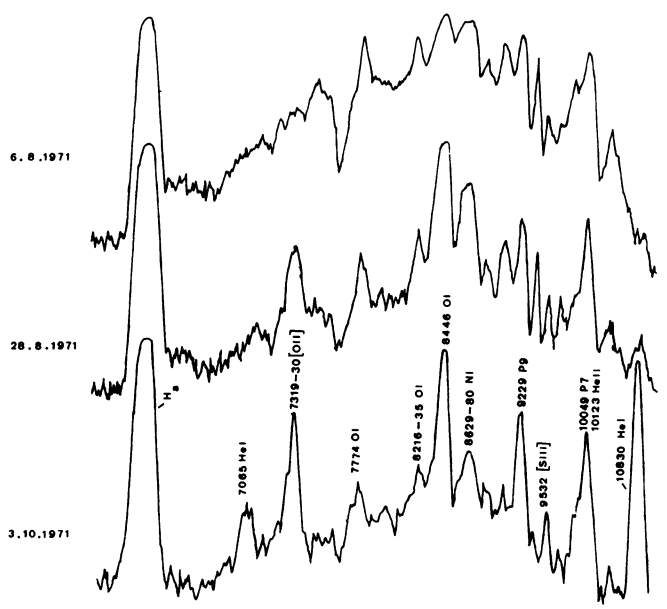

Fig. 5. Infrared tracings: note at the right end the strengthening of He I 10830.

TABLE I

Relative intensity and identification of emission lines in the blue-red spectra

	Element	July 14	Aug 27	Sep 22	Oct 28	Notes
7065.2	He I	–	–	20	2–3	1
6700.7	Fe II	–	4	–	–	
6678.1	He I	–	–	5	1	
6562.8	H	150	150	150	150	
6478	N III	–	3	3	5	2
6456	Fe II					
6363.9	[O I]	1	3	3	2	
6300.2	[O I]	1–2	4	5	4	3
6149	Fe II	1–2	1–2	–	2	4
6084.1	Fe II	1–2	1	–	–	
5991.4	Fe II	–	2	–	–	
5942	N II	3–4	2	2	2	
5875.6	He I	3–4	3	15	18	
5754.8	[N II]	1	20	25	20	5
5679.6	N II	1	2–3	15	8	6
5577.3	[O I]	0–1	1–2	2	1	7
5526.3	N II	0–1	1	0–1	–	
5316.6	Fe II	2–3	1–2	–	–	
5276.0	Fe II	2–1	1	0	–	
5234.6	Fe II	2–3	1	–	–	
5176–80	N II	3–4	2	4	–	8
5169.0	Fe II					
5047.7	He I	–	–	3	–	
5018.4	Fe II	4–5	2–3	2	–	9
5015.7	He I					
5006.8	[O III]	–	3	50	100	10
4958.9	[O III]	–	–	15	30	
4923.9	Fe II	4–5	2–3	2	–	
4861.3	H	30	30	30	30	11
4685.7	He II	–	–	2	2–3	12
4640	N III	1	8	25	8	13
4471.5	He I	–	–	1	2–3	
4363.2	[O III]	–	1	20	30	
4340.5	H	12	15	12	12	
4101.7	H	3	3	3	3	
3970.1	H	1	1–2	1	1	

Notes to Table I

1. The emission lines of He I attain the maximum strength at the end of September; then they decline.
2. Blend. The N III emission prevails during the last months.
3. [O I] 6364 and 6300 are weakly present since July 14.
4. Many Fe II lines are present during the first month after maximum. Then they fade.
5. [N II] 5755 brightens at the beginning of August. Still strong in December.
6. N II 5680 attains its maximum strength in September. Then it slowly declines.
7. Moderately strong in August–September.
8. Blend of Fe II, mult. 42 and N II.
9. Blend with He I. The Fe II components prevails.
10. The [O III] lines appear at the end of August and attain rapidly a very high strength. Their brightness is still rising in October, relative to Hβ.
11. The relative intensities of the emission bands have been estimated by comparison with Hβ assuming for this line an intensity equal to 30. In reality, as noticed by Bahng (1972) the strength of the Balmer lines decline during the nebular stage, while that of the [O III] lines remain nearly constant.
12. He II 4686, with a very peculiar profile, emerges during the nebular stage. It slowly strengthens.
13. Attains its maximum strength in September–October.

https://doi.org/10.1017/S0074180900010470 Published online by Cambridge University Press

TABLE II

Relative intensities and identifications of emission lines in infrared spectra

	Element	July 20	Aug 28	Oct 3	Notes
7231–36	C II	0–1	–		
7320–30	[O II]	1	6–8	10	1
7423–68	N I)	2	0–1	–	2
7476–80	O I)				
7772–75	O I	18	2–3	1–2	3
8216	N I	15	2–3	1	
8446	O I	30	25	20	4
8542	Ca II	5	0–1	–	5
8629	N I	8	1	–	
8680–703	N I	12	3	–	
8862.8	H (P_{11})	5	4	4	
9060.6	N I	8	3	3	6
9014.9	H (P_{10})				
9229	H (P_9)	15	8	8	7
9546	H (P_8)	3	1–2	0–1	
9821–62	N I	1	1	1	
10049	H (P_7)	15	8	8	
10395	N I	1–2	0	–	
10683–91	C I	4	1	–	
10830	He I	2–3	3	30	8

Notes to Table II

1. The [O II] forbidden doublet strengthens at the end of August and maintains a relatively high intensity from September to December when the observations are interrupted.
2. Wide blend of N I–O I. All the emissions of N I–O I (except λ 8446 Å) which are prominent in July, fade rapidly at the beginning of the nebular stage.
3. Very strong in July; declines in August.
4. This emission line of O I, excited by Lβ, maintains its strength until the end of September, then rapidly declines.
5. The identification is uncertain.
6. Blend of H (P_{10}) and N I. N I prevails in July; then the main contribution to the line is P_{10}.
7. Except for the first weeks, this line with intensity 8 was assumed as reference for the relative intensities of the other lines.
8. This is the strongest emission line of He I. The emission flashed to high intensity by the end of September.

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