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## Preliminary report on the infrared spectrum of Nova Serpentis 1970

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**Astrofisica.** — *Preliminary report on the infrared spectrum of Nova Serpentis 1970.* Nota di FRANCO CIATTI e AUGUSTO MAMMANO, presentata (*) dal Socio L. ROSINO.

RIASSUNTO. — Osservazioni spettroscopiche della Nova Ser 1970 compiute con un intensificatore S–1 nella regione λλ 6000–11000, mostrano la seguente evoluzione spettrale. Vicino al massimo si osservano righe di emissione e assorbimento di H, OI, CI, NI e FeII. Il tripletto infrarosso del CaII appare in emissione il 19 Feb., mentre H e K sono ancora larghe in assorbimento. La prima riga proibita, [NI] 10400, viene osservata il 20–21 Feb. In Marzo e Aprile si nota un allargamento delle bande: appare il secondo sistema di assorbimento. OI 8446 e la serie di Paschen sono intense, [OII] 7318–30 è già presente. La prima riga dell'HeI, osservata a λ 10830 il 26 Maggio, diviene la riga più intensa il 24 Giugno nella fase di « helium flash ». Alla stessa data HeII 10123, λ 7718 e le righe di [ArIII], [OII], [FeVII], crescono ancora d'intensità. L'eccitazione va aumentando fino a Sett., quando [FeVII] 8738 e [SIII] 9069–9532 si rinforzano. Il 26 Nov. il doppietto dell' [OII] è l'emissione infrarossa più intensa, mentre tutte le righe permesse, compreso HeI 10830 e la serie di Paschen sono nettamente calate di intensità.

## 1. INTRODUCTION

During the Colloquium held at Haute Provence, Swings (1964) pointed out the importance of extending spectral observations of Novae up to 1 micron. Indeed in this spectral region several strong lines can be found, which require similar excitation: HeI, [ArIII], [SIII]. Moreover [SII] and [OII] lines are present, indicating very low or intermediate densities respectively. Only in recent years new detectors allowed the observation of spectra in the 1 micron region. At Asiago Astrophysical Observatory we use an Image Tube with S–1 photocathode, obtained through the courtesy of the Carnegie Institution of Washington. The infrared spectra of Nova Serpentis 1970 have been obtained with the Camera IX (spectral range 7000–10900 Å, prismatic dispersion 440 Å/mm at λ 9000) and later on with the Camera VII (6000–10900 Å, 500 Å/mm at λ 9000) both attached to the Cassegrain focus of the 122 cm reflector. The spectral resolution ranges from 10 Å to 30 Å.

Our first observations were secured on February 19, 1970 shortly after the visual maximum which is reported to occur about February 17. We continued the observations until November 27; another spectrogram was secured on May 16, 1971. When the star faded to the 12th magnitude, exposure times as long as 4 hours were needed. The epochs of our infrared spectra are marked by short bars on the visual light curve, in fig. 1. In the same figure one may note the discrepancy between the visual and infrared light

(*) Nella seduta del 15 gennaio 1972.

curves of this star. Nova Serpentis 1970 appears to be a moderately slow nova, characterized by a rapid drop (about 5 mag) in the transition stage like XX Tauri (1927) and EU Scuti (1949). In infrared radiation, on the contrary, Geisel, Kleinmann and Low (1970) showed that a secondary maximum

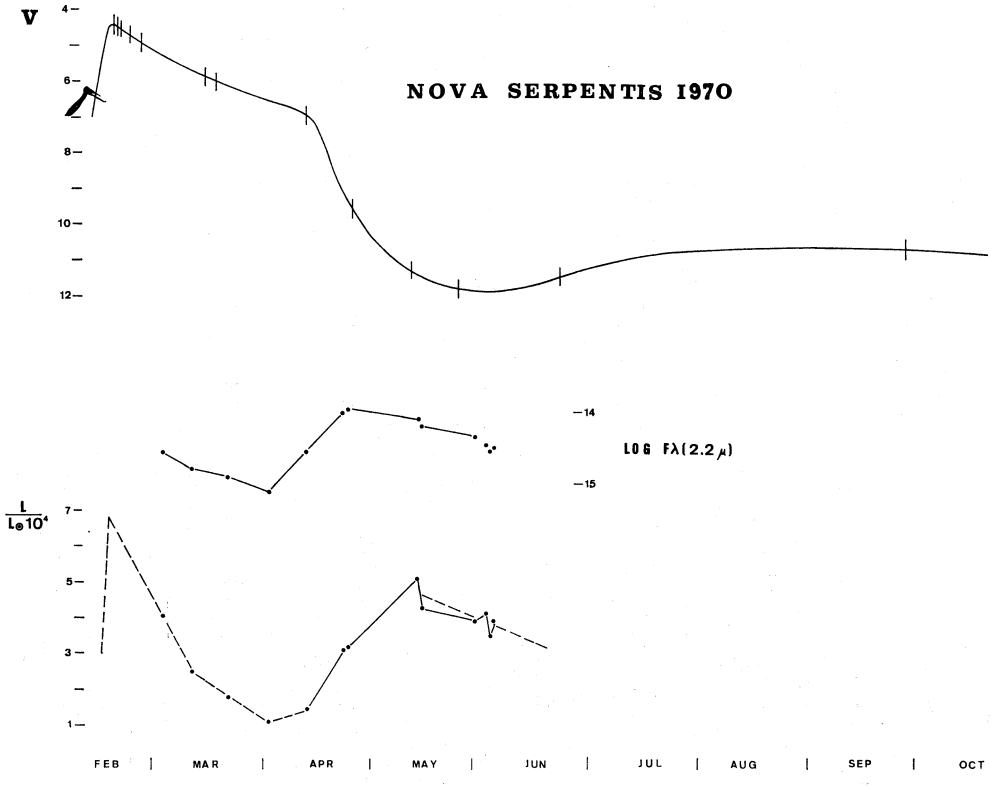


Fig. 1. – Visual light curve of Nova Serpentis 1970, compared with the infrared curves from Geisel, Kleinmann and Low (see text). Our infrared spectra are indicated with vertical bars.

occurred in May, about 100 days after the eruption. This maximum has a similar shape in all photometric bands from 1.25 to 22 microns, and has been explained with the formation of a circumstellar envelope of dust grains.

## 2. SPECTRAL EVOLUTION

The infrared spectral evolution of the Nova, shown in figs. 2 to 4, can be described as follows.

*February 19.* A few days after the outburst, many weak emission and absorption lines of H, OI, CI, NI, FeII are recorded on a rather overexposed spectrum. The absorptions belong to the system whose radial velocity is about —600 Km/s. The CaII infrared triplet seems already present in emis-

sion whilst H and K show on our spectra as broad absorptions. Indications of weak emission are reported by Nariai *et al.* (1970) and Grygar *et al.* (1970), but a clear evidence of H and K emissions was obtained at Asiago only some days later.

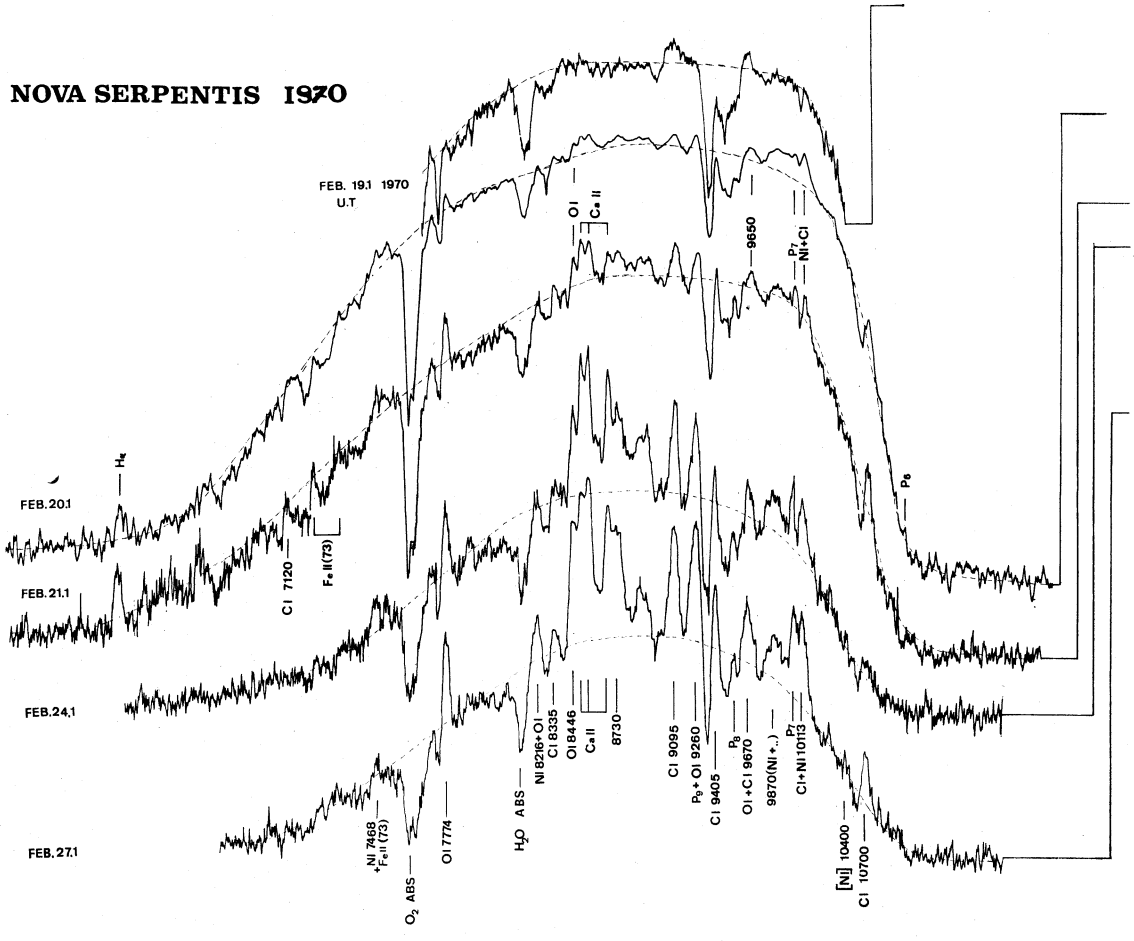


Fig. 2. – Microphotometer tracings of infrared spectra of Nova Serpentis 1970 (February 1970). Ordinates are transparencies.

*February 20–21.* The intensity of the emissions on the continuum is increasing. The auroral doublet of [NI] (3 F) at λ 10400 is probably already present; this first recorded forbidden line will become outstanding during the next months. The forbidden lines of [OI] 5577 and [NII] 5755 will appear only at the beginning of March, in spite of higher transition probabilities and comparable excitation potential, because of different opacity.

*February 24–27.* Due to a slight increase of excitation, stronger emissions of CI (8335, 9095, 9405, 9670, 10123, 10700), CaII (8498, 8542,

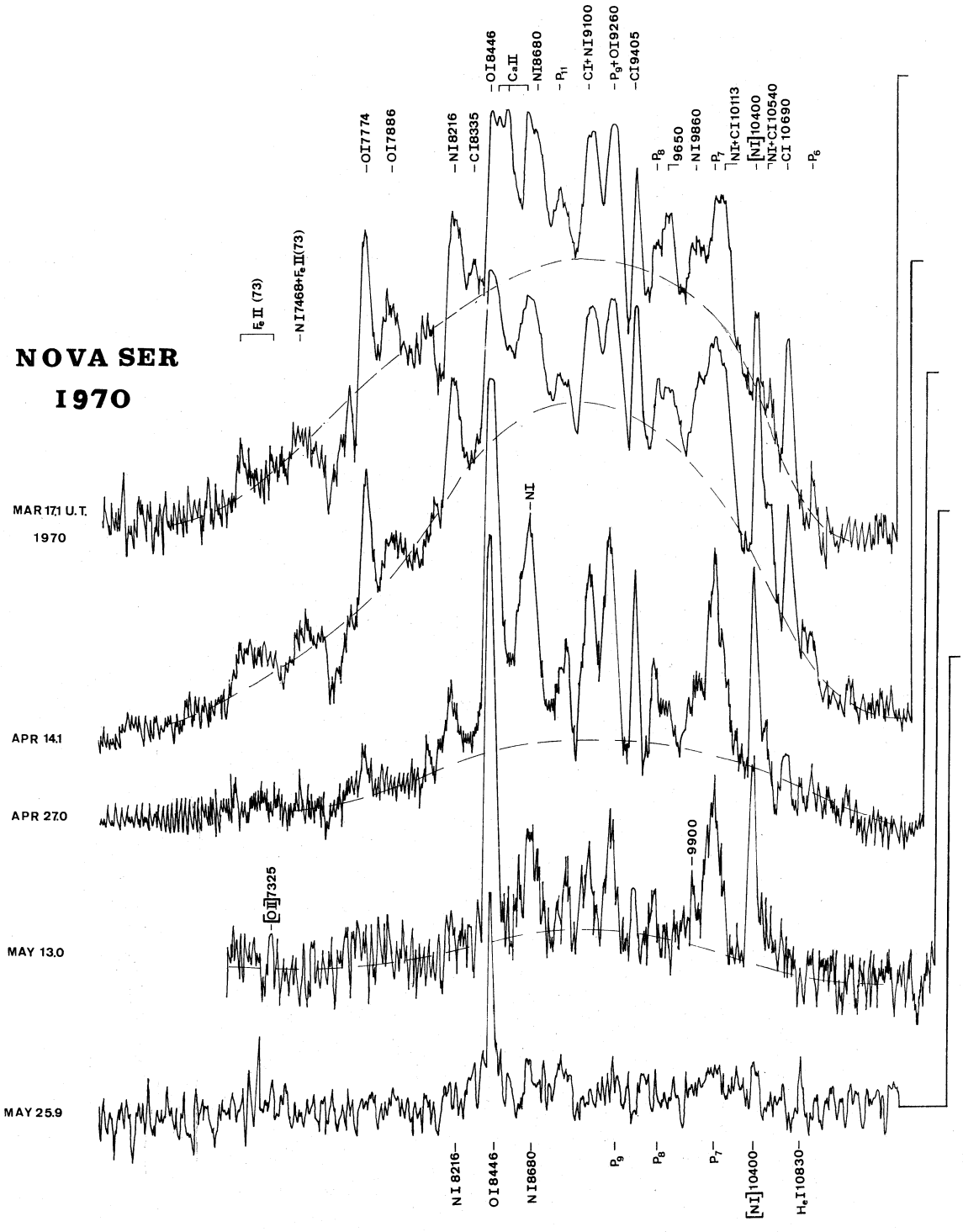


Fig. 3. – Microphotometer tracings of infrared spectra of Nova Serpentis 1970 (March–April 1970).

8663), HI ($P_6$ to $P_{10}$), OI (7774, 8222, 8446, 9263), NI (8216, 8680, 9870, 10113), FeII (multiplet 73) are visible. We remark that CI is well represented in this infrared region by fairly strong emissions among which the unblended lines at λλ 9095, 9405, 10700 are conspicuous.

*March 17–20* (1.5 mag below max.). A second absorption system appears with $v_r = -1700$ km/s and a remarkable broadening of emission bands is clearly visible. Lines of lower I.P., like CI and CaII, are becoming weaker

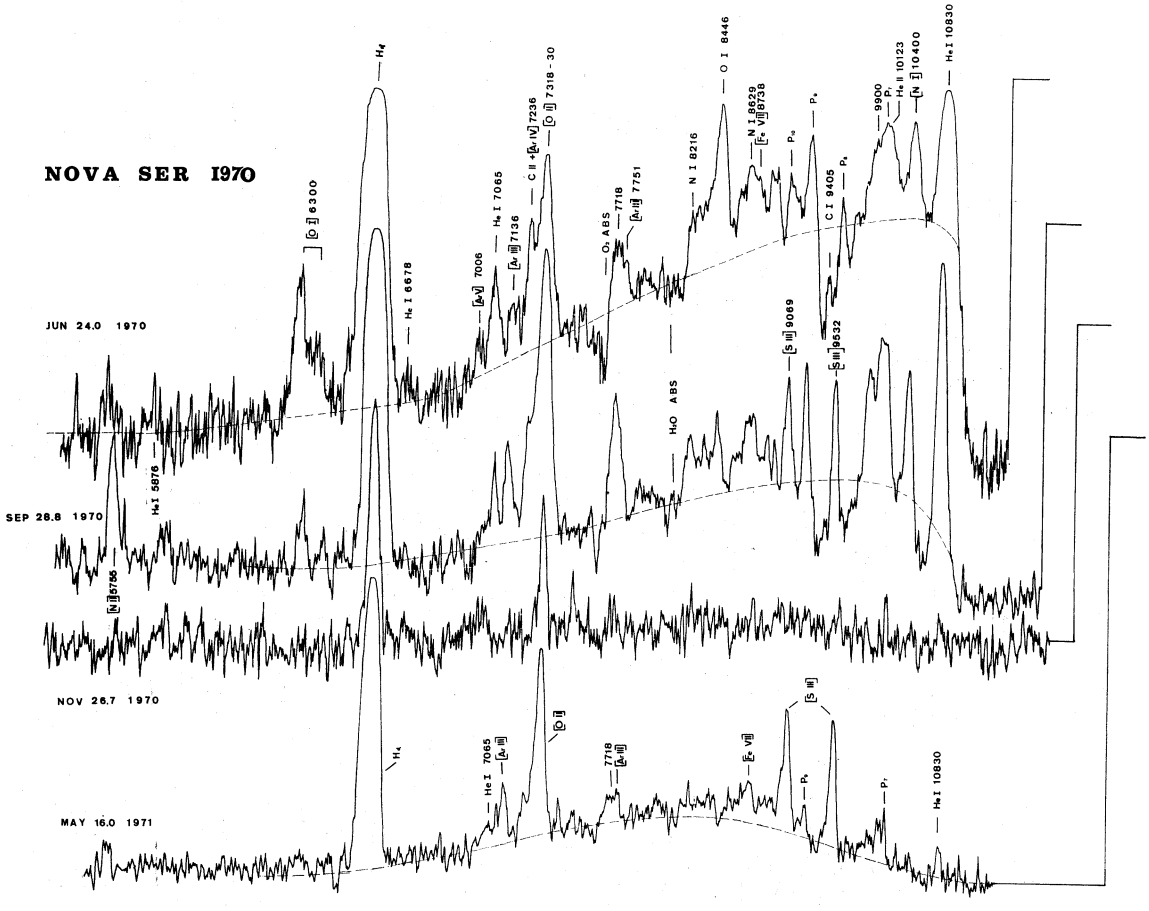


Fig. 4. – Microphotometer tracings of infrared spectra of Nova Serpentis 1970 (June 1970–May 1971).

(the intensity at CaII 8662 is constant due to other contributors), while NI 8680 is growing. When the excitation further increases, indications of dilution in the outer shells are given by the strengthening of OI 8446 in comparison with OI 7774, and the increasing [NI] 10400. Moreover lines of [FeII] (multiplets 13 F, 30 F, 40 F) might contribute to some blends (the η Car phase will be recorded in the red-visual only in May).

*April 14–27* (2.6–5.2 mag below max.). The spectrum of April 14 is the last showing weak absorption components. Still increasing excitation leads to stronger Paschen emissions, fading of the CaII triplet and weakening of CI and OI lines. The OI 8446 dominates the infrared spectrum because the fluorescence by Lyman β is now more effective. Another dilution effect is represented by the first appearance of a forbidden line of lower transition probability, namely [OII] 7318–30.

*May 13* (7 mag below max.). OI 8446 and [NI] 10400 achieve their maximum strength. We should expect at this time the appearance of the transauroral line 3466 [NI] (2 F), whose upper level is common to λ 10400 (3 F). Although our spectra do not cover that spectral region, we observed both lines in spectra of Nova Delphini 1967 taken during 1969. The predicted nebular transition at λ 5200 [NI] (1 F) is missing in both novae, in agreement with its very low transition probability. A similar behavior for the [NI] lines can be found in the observations of η Car by Thackeray (1967, 1969). FeII is mainly represented by forbidden lines since the permitted ones have remarkably weakened. NI, although of lower I.P., is still well represented since most of its transitions fall in this infrared region, as it is true for CI.

We are not able to identify a narrow line at about λ 9900, which is recorded till September. The absence of the emission at λ 6827 observed in RS Oph at an higher ionization stage, prevents identification of this line with [KrIII] 9902 of the same multiplet; actually the predicted transition probabilities are in the ratio 1 : 4 (Joy and Swings, 1945).

*May 26* (7.3 mag below max.). On this spectrum, although underexposed, we can note the first trace of HeI, with the line at λ 10830. The presence of HeI lines was reported at earlier date by Gehlich *et al.* (1970) and Grygar *et al.* (1971). According to the Asiago observations the first appearance of HeI occurred not earlier than May 13, since neither λ 5876 nor λ 10830 were yet visible.

*June 24* (7.1 mag below max.). HeI is well represented by λλ 6678, 7065 and 10830, this latter being very strong. As a consequence of increasing excitation, lines of neutral atoms like CI, NI, OI but λ 8446, have become barely visible, [OII] 7318–30 has remarkably strengthened. CII 7236 (mult. 3), [ArIII] 7136, 7751 (1 F) and possibly [SIII] 9069, 9532 (1 F), all characterized by I.P. close to that of HeI, are now also present. Lines of still higher excitation like HeII 10123 (mult. 2), [ArIV] (2 F), [ArV] (1 F) and [FeVII] 8738 (4 F) are observed.

Since the auroral and nebular [OIII] lines have now comparable intensities, $N_e$ is about 7.5 $10^5$ (assuming $T_e = 10^4$), and the transition probabilities do not play an important role for [OIII] 5007 and also for [SIII] 9532 and [ArIII] 7136 characterized by a similar value of critical density. In this case the emission per particle depends only on E.P. and cross sections. Since

both favour the [SIII] and [ArIII] lines, the observations showing λ 5007 as a much stronger line can be explained with the higher abundance of oxygen.

*September 29* (6.4 mag below max.). We observe the maximum excitation in the spectrum of the Nova. Actually all the previously reported lines are visible, with some significant variations of relative intensities. Permitted and forbidden OI and NI lines become fainter, while [NII] and [OII], HeI 10830, [ArIII] and notably [SIII] 9069–9532 are stronger. [FeVII] 8738 is still present.

The identification of a line near λ 7718, which now attains its maximum strength, is quite puzzling. Previously suggested identifications as CIV 7726 (Andrillat, 1964, a , b; Chincarini, 1964), FeII 7712 (Andrillat and Houziaux, 1970) both in Novae, or [SI] 7733 in BF Cyg (Dossin, 1959) are questionable. The lack of lines of CIII, some of which, like λ 9702, are particularly strong in WR stars (Kuhi, 1966; Bertola and Ciatti, 1972) and weakness of CIV 5802–12 are against the first suggestion. FeII 7712 (mult. 73) would require the presence of other lines of the same multiplet, which we do not observe. The low I.P. of SI (10.3 eV) implies an almost full ionization of this atom, as is inferred by the fall of CI lines (I.P. = 11.2 eV), the presence of [SII] 4069–76 and strengthening [SIII]. Some coincidences of lines suggest the transauroral transitions [SI] 4589–4506, but the observed intensity at λ 7718 is too strong in comparison with [OI] 6300 whose I.P. and abundance are larger and E.P. is lower.

*May 16, 1971* (7 mag below max.). The main features are now the following forbidden lines, listed according to their intensities: [OII] 7318–30, [SIII] 9069–9532, [ArIII] 7136–7751, [FeVII] 8738. Other lines are recorded at λ 7718, λ 9900, 7006 [ArV], 7236 CII+[ArIV], 10400 [NI]. The Paschen ($P_{10}$—$P_7$, this latter blended with HeII 10123) and HeI lines (10830, 7065, 6678) underwent a marked drop, as it is shown in fig. 4 and Table II. The spectrum of November 26, 1970 although underexposed, clearly indicates that HeI 10830 had already become much fainter than on September 29.

## 3. Concluding remarks

The emission lines observed in Nova Serpentis 1970 are listed in Table I. In order to get a better insight, we attempted to determine relative intensities of the most significant features (corrected for spectral sensitivity, instrumental effects and atmospheric extinction) which are given in Table II only for the spectra taken with the Camera VII. The cooling required by the S–1 detector, the long exposure due to its low sensitivity and difficulties in locating the continuum add more uncertainties to the usual difficulties of the photographic photometry, so that the values of Table II have to be taken with caution.

We are indebted to Drs. S. D'Odorico and R. Barbon who made available their program and observations of standard stars.

TABLE I.

*Emission lines in the infrared spectrum of Nova Serpentis 1970.*

| Ion | Mult. | $\lambda_{lab}$ | Ion | Mult. | $\lambda_{lab}$ |
|---|---|---|---|---|---|
| H ($P_6$) | | 10938 | N I? | 8 | 8594 |
| He I | 1 | 10830 | Ca II | 2 | 8542 |
| C I | 1 | 10691–83 | Ca II | 2 | 8498 |
| C I | 20 | 10548 | O I | 4 | 8446 |
| N I | 28 | 10539 | | | |
| | | | C I | 10 | 8335 |
| N I | 3F | 10404–395 | ..... | | (8300) |
| He II | 2 | 10123 | He II | 6 | 8236 |
| | | | O I | 34 | 8233–22 |
| C I | | 10124 | N I | 2 | 8216 |
| N I | 18 | 10113 | | | |
| | | | ..... | | (8100) |
| H ($P_7$) | | 10049 | | | |
| | | | ..... | | (8000) |
| ..... | | (9990) | | | |
| | | | O I | 64 | 7886 |
| ..... | | (9890) | | | |
| | | | O I | 1 | 7775–72 |
| N I | 19 | 9862–21 | | | |
| | | | Ar III | 1F | 7751 |
| He I? | 75 | 9702 | | | |
| | | | ..... | | (7718) |
| O I | 58 | 9677 | | | |
| C I | 2 | 9658 | Fe II? | 73 | 7712 |
| H ($P_8$) | | 9546 | He II? | 6 | 7592 |
| S III | 1F | 9532 | Fe II? | 73 | 7516 |
| C I | 9 | 9405 | N I | 3 | 7468 |
| | | | Fe II | 73 | 7462 |
| O I | 8 | 9266–62 | O I | 55 | 7476 |
| H ($P_9$) | | 9229 | | | |
| | | | O II | 2F | 7318–30 |
| C I | 3 | 9095–61 | | | |
| N I | 15 | 9060 | Fe II | 73 | 7320–08 |
| S III | 1F | 9069 | C II | 3 | 7236–31 |
| | | | Ar IV | 2F | 7236 |
| H ($P_{10}$) | | 9015 | | | |
| | | | Fe II | 73 | 7224–22 |
| Cr II? | 18F | 8930 | | | |
| | | | Ar III | 1F | 7136 |
| H ($P_{11}$) | | 8863 | | | |
| ..... | | (8875) | C I | 26 | 7118 |
| H ($P_{12}$) | | 8750 | He I | 10 | 7065 |
| Fe VII | 4F | 8738 | Ar V | 1F | 7006 |
| N I | 1 | 8680 | ..... | | (6835) |
| Ca II | 2 | 8662 | He I | 46 | 6678 |
| N I | 8 | 8629 | Hα | | 6563 |

TABLE II.

*Relative intensities of emission lines.*

| LINE | Sp. A88 (June 1970) | Sp. A179 (Sept. 1970) | Sp. A338 (Nov. 1970) | Sp. A586 (May 1971) |
|---|---|---|---|---|
| $H_\alpha$ 6563 | (236) | (315) | (157) | (251) |
| He I 6678 | 1 | 1 | 1 | 1 |
| [ArV] 7006 | 2–3 | — | — | 1 |
| He I 7065 | 9 | 7 | — | 6 |
| [ArIII] 7136 | 5 | 13 | — | 11 |
| CII + [ArIV] 7236 | 12 | 15–16 | — | 8 |
| [O II] 7318–30 | 34–35 | 111 | 43–44 | 46 |
| λ 7718 | 9–10 | 21 | 17 | 8 |
| [ArIII] 7751 | 4 | | | |
| N I 8216 + He II | 9 | 10 | — | 2 |
| O I 8446 | 100 | 11–12 | — | 1 |
| N I 8629 | 24 | 20 | 23 | — |
| [FeVII] 8738 | 16 | | | 6–7 |
| H ($P_{11}$) 8863 | 17 | 4–5 | — | — |
| H ($P_{10}$) 9015 | 16 | 5 | — | — |
| [SIII] 9069 | 7 | 12 | 27–28 | 22–23 |
| H ($P_9$) 9229 | 21 | 19–20 | — | 3 |
| C I 9405 | 4 | 2 | — | — |
| H ($P_8$) + [SIII] 9532 | 16 | 23 | 12 | 28–29 |
| λ 9900 | 36 | 28 | — | — |
| H ($P_7$) 10049 | 45 | 45–46 | 36–37 | 19–20 |
| He II 10123 | 40 | 42–43 | | |
| [N I] 10400 | 48 | 24 | 10–11 | 3 |
| He I 10830 | 157 | 142 | 16 | 4 |

From the description of the spectral evolution, and with the aid of Table II, we infer that the excitation in the ejected nebula increased till the end of September 1970. Indeed we observe, after this date, a weakening of most HeI and HeII lines. This is confirmed by the fading in 1971 of [FeVII] 8738 and 6085 in comparison with [OI] 6300–6363. The apparent increase of some

forbidden lines in comparison with the permitted ones cannot be due to a further increase of excitation, because the I.P. of HeI, SII and ArII are about the same. Since the E.P. of HeI 10830 (1.1eV) is less or equal to those of forbidden lines, its fading should mean that depopulation of the metastable lower level (E.P. = 19.73 eV), from which this line is excited by collision, occurs at a faster rate than recombination of the ions responsible for the forbidden transitions.

Observations of this Nova will be carried on as far as possible. A more detailed discussion of its spectral evolution in the wavelength range 3400–11000 Å will be given in a forthcoming paper.

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