SPECTROGRAPHIC OBSERVATIONS OF NOVA DELPHINI 1967

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RIASSUNTO. — Vengono dati i risultati delle osservazioni spettrografiche compiute durante il 1967-68.

Si discutono le identificazioni delle righe e la comparsa dell'[OI] e dell'HeI. Viene descritto lo sviluppo spettrale della nova, alcune peculiarità, nonché l'andamento delle intensità delle emissioni e degli assorbimenti in relazione al massimo di Dicembre. L'indebolimento delle emissioni rilevato il 12 dicembre 1967, viene correlato con l'avvenuta eiezione di materia, precedente il massimo.

Le misure di velocità radiale per H, FeII, TiII, CrII, SrII, ScII, e l'esame delle componenti di assorbimento, permettono di evidenziare i diversi inviluppi circondanti la stella. Inoltre si è notato che la differenza fra le velocità medie delle emissioni dell'idrogeno e dei metalli, sale da circa 15 a 45 km/sec nella fase dopo il massimo di dicembre.

SUMMARY. — The results of spectrographic observations performed during 1967-68, are reported.

The identifications of the lines and the appearance of [OI] and HeI are discussed. The AA. have examined the spectral development of the nova, its peculiarities and the behaviour of the intensities of the emission and absorption components with regard to the maximum of December. The weakening of the emissions, observed on December 12, 1967, is related to the ejection of matter preceding the outburst.

The radial velocities of H, FeII, TiII, CrII, SrII, ScII, and the consideration of their absorption components, make evident the various shells enveloping the star. We have also observed that the difference between the mean velocities of the hydrogen and metal emissions increases from about 15 to 45 km/sec in the phase after the outburst of December.

1. - OBSERVATIONS

The observations of Nova Delphini 1967, have been performed at the Merate Observatory with the Zeiss spectrograph (35 Å/mm at H_γ), in the spectral range λλ 3850-6570 Å.

The data regarding our spectra are reported in Table I.

(*) Ricevuta il 23 Dicembre 1969. Testo definitivo il 19 Gennaio 1970.
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TABLE I

Spectrum n.	Date			J.D. 2430000+	Spectral* Range
2465	1967	Sept.	24	9758.40	V
2466		»	24	9758.45	V
2467		»	25	9759.33	V
2468		»	25	9759.44	R
2469		»	26	9760.34	V
2471		Oct.	5	9769.31	V
2472		»	5	9769.36	V
2473		»	11	9775.32	V
2474		»	11	9775.37	R
2476		»	18	9782.28	V
2477		»	18	9782.35	R
2481		»	19	9783.27	V
2483		»	19	9783.32	R
2489		»	20	9784.26	R
2494		»	23	9787.30	V
2511		»	25	9789.26	R
2519		Nov.	21	9816.23	V
2521		»	21	9816.30	R
2530		»	22	9817.23	V
2532		»	22	9817.29	R
2535		»	23	9818.25	V
2546		Dec.	12	9837.23	V
2555		»	13	9838.24	R
2556		»	13	9838.28	V
2558		»	14	9839.24	R
2578		»	18	9843.23	R
2579 bis		»	20	9845.21	R
2579		»	20	9845.22	R
2581		»	20	9845.26	V
2605		»	21	9846.28	V
2607	1968	Jan.	4	9860.23	R
2608		»	4	9860.26	V
2609		»	8	9864.24	R
2623		»	18	9874.24	V
2630		»	19	9875.23	V
2631		»	23	9879.22	R**
2632		»	25	9881.23	R**
2671		May	14	9990.55	V
2680		»	17	9993.54	R
2682		June	25	10032.54	R
2685		July	4	10042.48	V
2690		»	10	10047.52	V
2692		»	11	10049.49	V

* $V = \lambda\lambda$ 3850 - 5020 Å; $R = \lambda\lambda$ 4100 - 6570 Å.
** 70 Å/mm at H_γ.

The complete list of our identifications and the tables of radial velocities are given apart (GALEOTTI and PASINETTI 1969).

We have excluded the study of the Ca II lines which have been examined in detail by FEHRENBACH and PETIT (1969).

2. - IDENTIFICATIONS

All spectra have been examined on microphotometric tracings and directly on comparator.

We have followed with attention the appearance of the forbidden lines of [O I] for which various AA. give different data.

The auroral line at λ 5577 appeared on our spectra surely on October 20 1967; its appearance is very uncertain (if present, the line is very weak) on the spectra of October 18 and 19, as reported by MAMMANO and ROSINO (1967); on the contrary FEHRENBACH et al. (1968a) noticed it since August 8.

λ 6300 is always present (our observations began on September 24).

λ 6364 is uncertain on the spectrum of December 20: a large emission band of Fe II, Si II is probably blended with [O I]; this line is certainly present on January 8, in agreement with SEITTER (1969) who reports its appearance on January 9. However our spectra have a low dispersion in this region. Fehrenbach et al., Mammano and Rosino noted this line, for the first time, respectively on October 2 and 23.

We have observed the [O I] emissions also during the outburst of December; moreover these lines are strengthening with time from December to January: on the spectrum of December 14, the 5577 line has a weak intensity, comparable with that of November 21; on December 18 and 20 the emission has increased but it is weaker than Fe II λ 5535; on January 8 the intensity ratios of these two lines are reversed.

The various AA. give different data also for the appearance of the helium; HUTCHINGS (1969) observed it at the end of March 1968, FEHRENBACH et al. (1968b) on June 7. We noted the He I at λ 5876 in coincidence with the maximum on December 14, 1967; Mammano and Rosino in the same period, have remarked « a slight strengthening » of this line.

On December 20 a large emission at about λ 5755 has appeared, which we identified as [N II]; it was not present on December 14 and very uncertain on December 18 being the spectrum overexposed in that region. In the period of the maximum also the profiles of the [N II] and [O I] emissions are entirely different, as reported by WALLERSTEIN (1968) for an observation of June 5 indicating that [N II] radiation comes from a hotter region than that in which the [O I] originates.

We have not observed other forbidden lines until July 1968; however few plates were taken in this last period. On the spectra of July 4-11, besides H, Fe II, He I, Si II, other typical emissions of the 4640 stage, are visible: N II, N III, 4640 band, C II, [Fe II], [O III]. The Balmer absorption lines have disappeared, moreover the Fe II emissions are weakened and enlarged giving place to broad emission bands.

3. - Results

Spectral analysis. - We have performed a visual inspection of all the plates and an analysis of their microphotometric tracings to follow the important spectral changes and the development of the nova.

In the period of our observations, we can distinguish the following phases (the dates are referred to our spectra; eventual changes may have occurred at days not covered by our observations):

1. - 1967, September 24 - November 23.

During this period substantial changes in the spectrum have not been observed.

Besides the Balmer lines, those of Fe II, Ti II, Na I D, Ca II H and K, are very strong. Sometimes the Fe II and Ti II lines are stronger than those of the hydrogen. All emissions are accompanied, on their violet side, by strong absorption lines shifted of some Angstroms. The slowest systems have the strongest intensities.

The radial velocities show that there are present four or five shells of matter ejected with different velocities and forming envelopes around the star. From the absorption components of hydrogen, the presence of five shells is deduced, whose greatest expansion velocity is of about — 600 km/sec (see Table II, Galeotti and Pasinetti 1969).

In the case of Fe II and Ti II four and five shells respectively are observed, with greatest velocities about — 480 km/sec.

Usually the absorptions are stronger than the emissions, both for hydrogen and metals, save H_α whose emission is always very strong. However this structure is not entirely stationary and, in the case of H, it is not always uniform for all lines.

The following exceptions have been observed:

September 24. - H_β shows the emission slightly stronger than the absorption; the reverse occurres in the metals.

September 26. - H_β as Sept. 24; in H_γ the absorption is much stronger than the emission; in H_δ the intensity of the absorption is slightly stronger.

October 11. - H_β and H_γ as before; in H_δ the absorption and the emission are of the same intensity.

November 21. - The emissions of Sc II have increased.

On November 23 all the emissions of hydrogen and metals have radial velocities higher than those of other days. This fact could be explained by the slight increase of brightness of the nova, occurred on November 23, according to TERZAN (1968, Fig. 2, curve b).

The spectrum appears nearly unchanged until December 12.

2. - Phase of the second outburst.

In coincidence with the maximum of December at $3^m.4$, the photosphere has ejected repeatedly shells at velocities higher than 1000 km/sec.

Considering the radial velocities of hydrogen, we note besides the preexisting shells, other four absorption systems with the highest observed velocity of about − 1140 km/sec; Fe II and Ti II show respectively four and three new absorption systems with the highest expansion velocities of about 1180 and 860 km/sec.

December 12. - The spectrum reveals that the hydrogen is predominant. Some absorption lines of the metals have weakened, particularly some of Fe II; for instance the Fe II λ4352 line, whose intensity was comparable with that of H_γ, has now an intensity equal to about one half. The emissions have greatly weakened; however they have not totally disappeared as reported by BIDELMAN (1967) for December 14.

H_β, H_γ, H_δ also show absorptions more intense than the emissions which in the two last lines are scarcely visible.

On the contrary the emission of Sr II at λ 4078 seems to be remained strong.

December 13. - The emissions are always present; in particular the emission lines of Fe II at λλ 5317, 5169, 5018, 4924 are rather strong; however the absorptions are much more intense.

H_β has a strong emission, but less intense than the absorption; H_γ and H_δ have a very weak emission. Also Ti II emissions are present together with very intense absorptions.

December 14. - We have observed the emissions also in this spectrum. The emission intensity of H_β is similar to that of the absorption; on the contrary the absorption of H_γ and H_δ is more intense than the emission. The emissions of Na I, Fe II (at λλ5317, 5069, 5018 they are slightly weaker than the absorption) and Ti II are also well visible. The metallic absorption lines are very intense.

December 18-21. - Important changes occurre in the spectrum. Several absorption systems like bands, with a complex structure, and broad emissions are visible (in particular H_δ presents a very broad emission).

On December 18 the absorptions of Fe II, Ti II, Cr II are yet stronger than the emissions. From December 18 to 21 the emissions are strengthening. On December 20 H_α has a very strong emission and a very weak absorption; in H_β also the absorption is weaker than the very broad emission. The sharp emission components of the metals are spreading and strengthening in time. Moreover some emissions, which were very weak in October, are visible now as large bands, for example the lines Ti II λ 5072 and Fe II λλ 5425, 5101, 4993. [O I] emission at λ 5577 is also strong.

On December 21 the emissions are prominent compared to the absorptions although in the metals these are yet strong; moreover the emissions are sometimes more resolved and sharp than those of December 20.

H_β has a very strong emission and a weak absorption which is very faint in H_γ also.

3. - 1968, January-May.

After December 21, the successive plate was taken on January 4. The spectrum is very much changed; the absorption lines have a complex structure, variable from day to day; strong and broad emissions are associated with large absorptions.

The metals are weakening and are much less intense than hydrogen; their emissions, still prevailing in comparison with the absorptions, are weaker than those of December 20.

On January 8 the [O I] emissions are very strong and rather sharp; the He I λ 5876 and [N II] are also visible.

No observations were secured from January 25 to May 14; the spectrum seems nearly stationary. The behaviour of the hydrogen lines is changed, in fact the emissions have much spread and show a very broad wing on the red-side.

4. - July.

Our observations of this period are few and do not cover a wide range of time. The only spectrum of June 25 is underexposed, therefore a careful qualitative analysis is not possible.

On July 4 the spectrum appears to be very much changed; most of the metal lines have disappeared and only weak residues of their emissions remain still visible.

The hydrogen emissions are very broad; moreover we note the large emissions of C II, N II, N III, typical band at λ4640, He I, [Fe II], [O I], [O III], [N II].

Radial Velocities. - In Figs. 1 and 2, the heliocentric radial velocities of H, Fe II, Ti II and Cr II are given (see Table II of our preceding paper). From the outburst of December the emissions are very large, particularly in the case of hydrogen; therefore we have determined their radial velocities measuring the beginning and the end of each emission and, when possible, the wavelength of maximum intensity. As reported in our preceding paper, the probable errors have usually a value of few km/sec both for emissions and absorptions, with the exception of some plates secured after the maximum of December in which the probable error amounts to about 20-30 km/sec.

Comparing the single lines of hydrogen, from which the mean radial

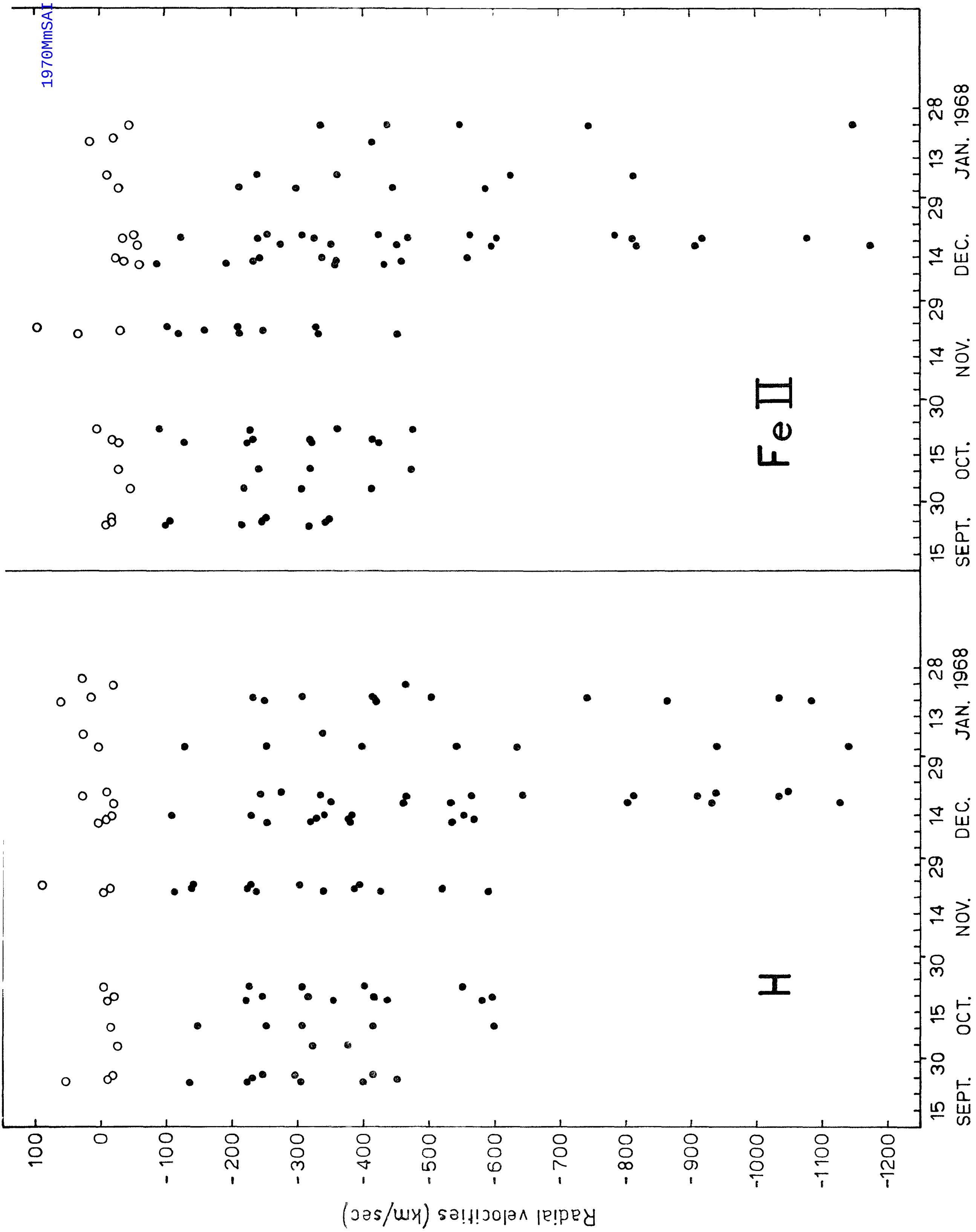

FIG. 1

Radial velocities of *H* and *FeII*. ○ emissions; ● absorption systems.

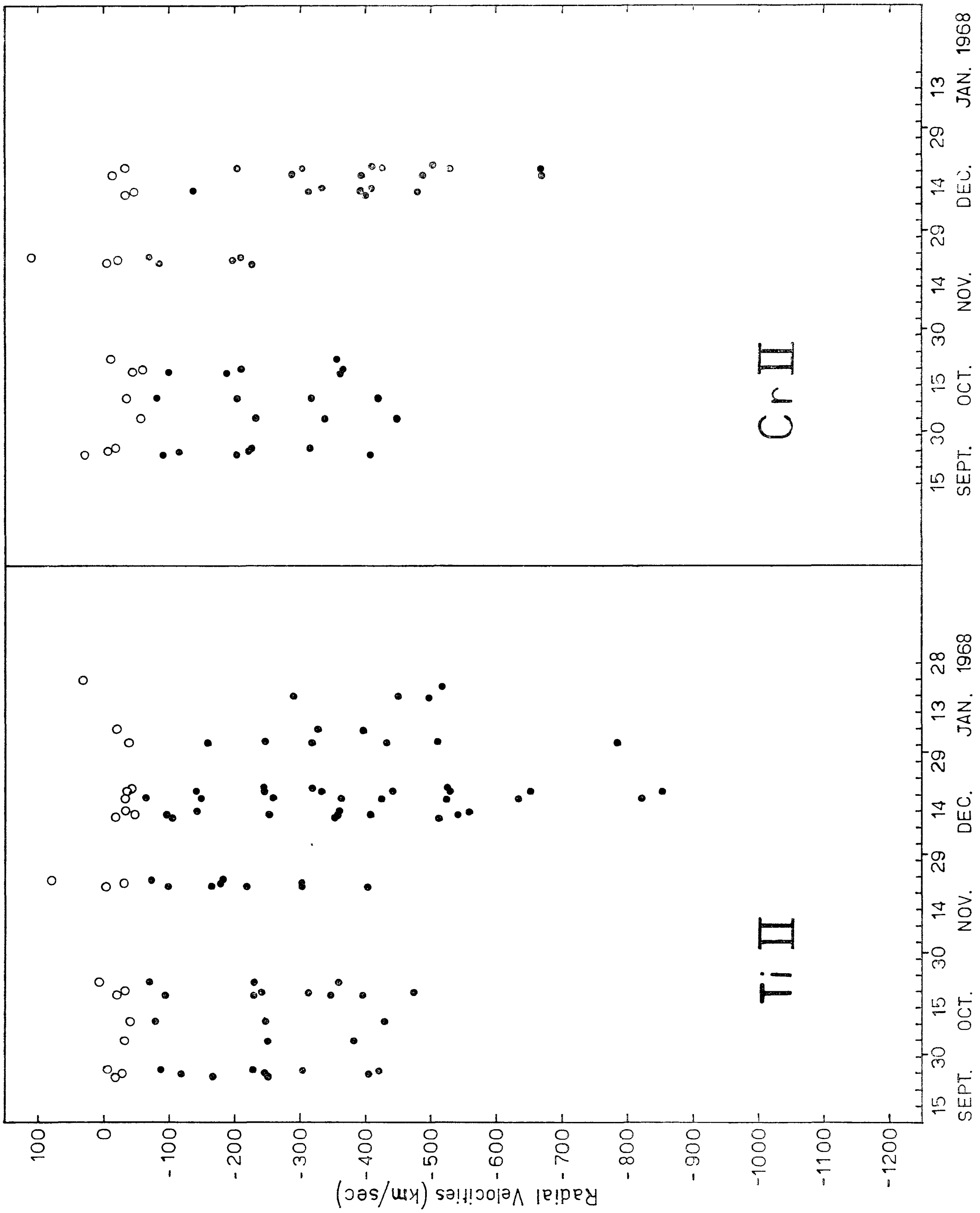

FIG. 2
Radial velocities of *TiII* and *CrII*. ○ emissions; ● absorption systems.

velocities given in Fig. 1 have been computed, we have remarked that the H_δ emissions are generally more negative than the H_γ and H_β after the maximum of December (H_α has only few observations). This effect may be real because of the uniform method used for the measures: it could be confirmed from spectra showing the higher members of the Balmer series.

The mean emissions of hydrogen become more positive after the outburst of December; however the results of this period have a higher dispersion, owing to the difficulty of the measures.

For the absorptions, we have not noticed remarkable differences in the radial velocities derived from the different lines of hydrogen; therefore we have averaged the values of H_β, H_γ, H_δ, omitting the few measures of H_α.

From Fig. 1, we can remark that the second shell presents a velocity slightly more negative after the maximum of December. The fourth and fifth shells show a high dispersion of dots, in particular the observations of this last shell are mostly due to single lines (H_β is never present).

The low dispersion, the difficulty of the measures after the maximum and the few spectra, do not permit to follow with accuracy the development of some new shells, with velocities of about − 650, − 780, − 920, − 1080 km/sec; we can limit ourselves indicating only their presence.

Owing to the few measures of H_α and to the low dispersion in this spectral region, it is not possible to follow the development of the shell at this frequency; however our measures agree well with the velocities derived from the other hydrogen lines; in the epoch of maximum the velocities of H_α reach a value of about − 1320 km/sec.

The velocities deduced from the emissions of the metals show a very good agreement for the different elements. On November 23, 1967 we notice that all the emissions are systematically red-shifted of about 90 km/sec.

We have compared the mean radial velocities of the emission lines of hydrogen with those of the metals. From this comparison a difference can be remarked between the velocities of the phase preceding the outburst and those of the phase following it, therefore we have considered separately the two periods. During the phase Sept. 24-Dec. 14 the velocity difference of the emissions of hydrogen and metals is 15.2 km/sec (H more positive) which is in good agreement with the values given by HUTCHINGS (1969) and by YAMASHITA (1968); in the phase Dec. 18-Jan. 25 this difference increases to 45.0 km/sec, mostly due to the more positive velocities of hydrogen. This observed difference seems to be real for the homogeneity of the method of measuring and for being higher than the errors. This effect supports the hypothesis that also during the phase of maximum, the hydrogen and the metals originate their emission lines in different layers of the atmosphere, at different temperatures.

We have considered separately the absorptions of the metals because they present some small differences of velocity. The graphs of Sc II and Sr II are not given (see Table II of our paper I) being their behaviour quite similar to that of the elements discussed in detail.

The envelope with the lowest velocity is present till the outburst of December in all the metals; after, it seems to extinguish. It is possible to separate two shells of Ti II whose velocities are grouped around – 90 and – 160 km/sec; Fe II, save one day, has only the lower velocities. From the inspection of the graphs we can remark that Cr II, with E. P. similar to Fe II's, shows lower velocities, like Fe II; Sc II has a behaviour very similar to that of Ti II having about the same E. P.; the shell of Sr II although with few observations, seems to have only low velocities.

The shell with velocity of about – 220, – 240 km/sec shows a behaviour nearly identical for all the metals; Ti II has a very low dispersion of the observational dots. Only Cr II (the metal with the highest E. P.) seems to have velocities more positive, in agreement with its behaviour in the preceding shell.

The shell with velocity about – 330 km/sec, is very similar to the precedent; velocities more positive occurre in Cr II, only from the outburst.

The shell with velocity of about – 420, – 450 km/sec has a greater dispersion of the observational dots, especially in the case of Fe II; Ti II seems to have more positive velocities; Cr II as in the preceding shell. For Sr II this shell has appeared only from the maximum of December.

In the phase of the outburst some new shells have appeared for the first time. The velocities are different for the various metals: Fe II about – 580 km/sec with a great dispersion of the observational dots. Ti II about – 520 km/sec with lower dispersion; few points of Cr II show a velocity of about – 500 km/sec; Ti II, Cr II, Sc II have many velocities in good agreement at about – 650 km/sec. Moreover our measures emphasize the presence of other shells with velocities ranging from – 800 to – 1100 km/sec.

From our study it does not seem possible to confirm the hypothesis suggested by Hutchings that the line spectrum during 1967 is formed in a continuous extended atmosphere as opposed to separate shell.

The AA. wish to thank Miss Amalia Bonfanti and Mr. Renzo Valtolina for their valid collaboration in the reduction work.

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