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The Evolution of the Nova LV Vulpeculae Spectrum*

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The nova LV Vulpeculae has been discovered on April 15, 1968 as a star of 5.6 mag. and reached the maximum light of $4{,}^m35$ on April 17 (Raikova, 1981). We have taken 15 spectra of the nova at the Crimean Astrophysical Observatory. They cover the wave-length region 3600 Å-5000 Å with a mean dispersion 37 Å/mm. Additional data about the spectra are given in Table 1. Other 12 spectra, obtained at Haute Provence Observatory, have kindly been placed at our disposal by Prof. Fehrenbach and Dr Andrillat (Table 2). The spectra of dispersion 9.6 Å/mm cover the range 3500 Å-5000 Å, and those of dispersion 12.4 Å/mm cover the range 4100 Å-6700 Å. The French spectra are referred to the evening date (Fehrenbach, Bloch, 1968) and in April the nova is observable past midnight.

All the spectra have been traced in darkening with enlargement ×100 for the Crimean spectra and ×24 for the French ones, the comparison spectrum

Table 1

Date 1968	J. D.	Emulsion	Slit width, mm	Spectrum width, mm	Exposure time
19. IV	2439966.49	OaO	0.2	0.8	58^m
22. IV	969.46	IIaO	0.15	0.8	37
23. IV	969.51	IIaO	0.15	0.8	1^h09^m
24. IV	971.47	OaO	0.2	0.8	53
26. IV	972.57	OaO	0.2	0.8	37
27. IV	973.58	OaO	0.2	0.8	45
2. V	978.57	OaO	0.2	0.6	1 15
13. V	990.41	A500	0.2	0.8	55
16. V	993.51	A500	0.2	0.6	2 15
22. V	999.49	A500	0.2	0.7	1 05
6. VI	2440014.47	A500	0.2	0.4	3 04
19. VI	027.47	A500	0.2	0.4	4 00
9. VII	047.55	A500	0.3	0.4	2 36
14. VII	052.54	A500	0.3	0.4	3 08
27. VII	065.34	A500	0.3	0.4	3 26

* In this paper the astrophysical unit angstrom for wave-length has been used; $1Å = 10^{-10}$ m.

Table 2

Spectrum number	Date 1968	Emulsion	Dispersion, Å/mm	Exposure time
W 4259	16. IV	IIaO ch	9.6	24^m
W 4260	16. IV	103aF	12.4	24
W 4263	17. IV	IIaO ch	9.6	1^h04^m
W 4264	17. IV	103aF	12.4	32
W 4270	18. IV	103aF	12.4	20
W 4271	18. IV	IIaO ch	9.6	30
W 4276	19. IV	103aF	12.4	50
W 4277	19. IV	IIaO ch	9.6	40
W 4280	22. IV	103aF	12.4	32
W 4281	22. IV	IIaO ch	9.6	38
W 4286	24. IV	IIaO ch	9.6	1 24
W 4288	24. IV	103aF	12.4	50

being registered after re-running of the paper. From the tracings we have followed the evolution of the nova spectrum. The darkening profiles of H_β are shown in Figs 1 and 2.

The first of the available spectra has been taken on *April 17.08* (Fehrenbach and Bloch, 1968) some hours before the light maximum (Raikova, 1981). The premaximum spectrum is characterized by broad and diffuse absorption lines of HI, CaII, FeII, CrII, TiII, SrII, OI, FeI, NaI. The CI lines are unusually strong for a F-type spectrum (CI 4771 Å is as intensive as TiII 4779 Å and TiII 4805 Å). Considerable emission is observed only in H_α. Faint emission is present in H_β, H_γ and the strongest lines of FeII.

On measuring the shift of 36 lines of different atoms except the hydrogen, the radial velocity — 670 km/s$\pm$11 km/s has been obtained. The accuracy of a single measurement is relatively low because of the great profile width. Within the limits of the scattering there is no discernable dependence of V_r on the intensity or excitation energy of the line. For example, the high excitation lines SiII 6347 Å and SiII 6371 Å have nearly the same displacement as the neutral sodium resonance line NaI 5889 Å. Also, the strong line FeII 4923 Å shows the same radial velocity as the faint one CI 5793 Å. This may be an indication that there is no noticeable velocity gradient in the layer where these lines originate. The symmetrical shape of the line profiles is another indication.

From the Balmer line displacements the following radial velocities have been obtained: —876 km/s (H_α), —759 km/s (H_β), —720 km/s (H_γ), —692 km/s (H_δ), and —654 km/s (H_8). This obvious velocity gradient does not contradict the conclusion drawn above. On the one hand, the first Balmer lines have a certain emission which could "fill" the red wing of the line and shift the observed line centre to the violet. On the other hand, the dominating amount of hydrogen atoms and the high transition probabilities of the Balmer lines make possible the contribution of more distant gas to the line formation. Maybe this gas has been ejected before the nova outburst or at its very begining. The velocity gradient could be caused either by a decrease of the ejection velocity, or by radiative acceleration of the gas. The second explanation seems more plausible, because on April 18 and later there is no noticeable velocity gradient neither from metallic lines nor from the Balmer ones, the distant absorbing gas having probably rarefied and cooled.

April 18. Two absorption line systems predominate. Their shifts correspond to —780 km/s and about —1340 km/s, respectively. Mammano et al. (1969)

consider them as premaximum and principal systems, and later on Mammano and Rosino (1970) call them simply absorption systems I and II. After a careful study of the spectra we conclude that on April 18 and the following days we deal with the principal ($V_r = -780$ km/s) and diffuse-excited (V_r

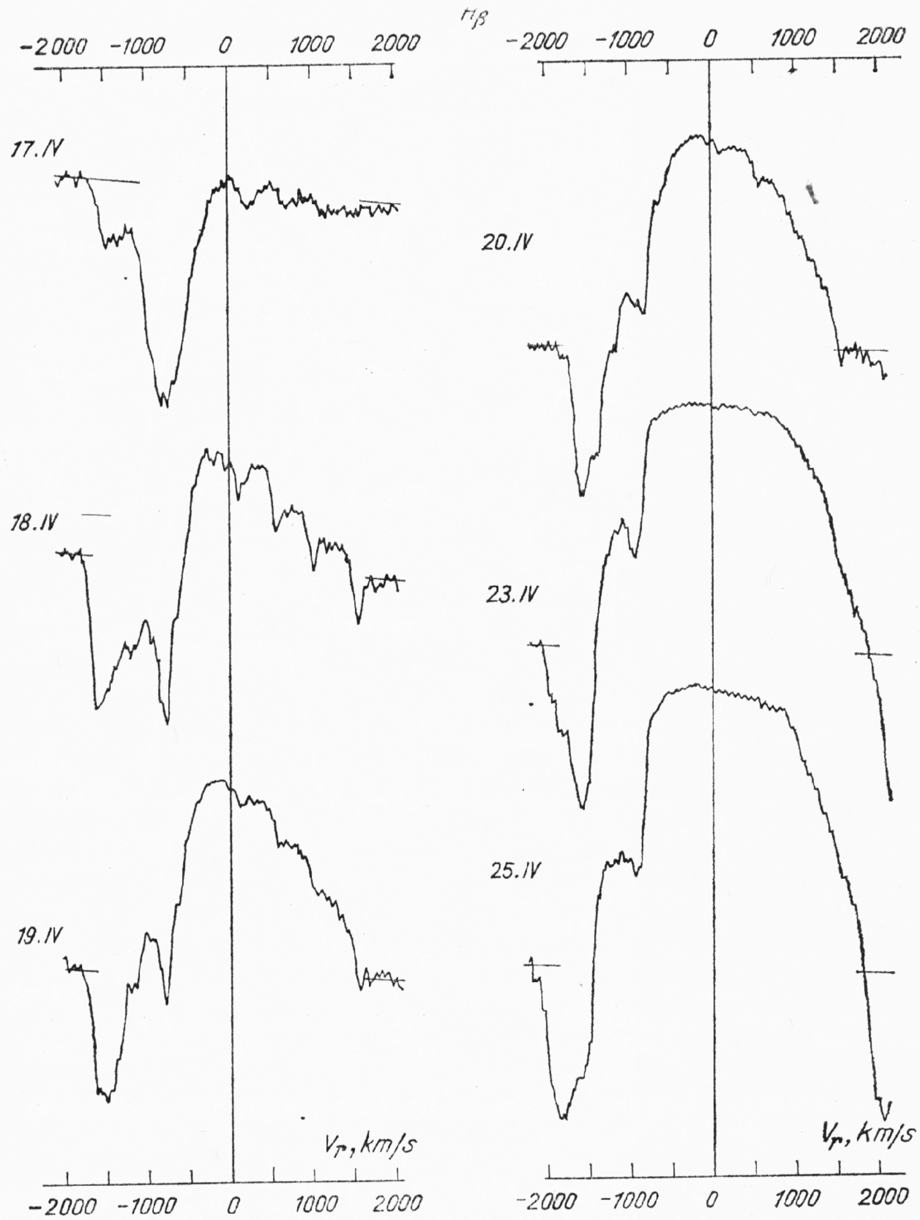

Fig. 1. Photographic darkening profiles of Hβ from the French spectra (original dispersion 12.4 Å/mm)

$= -1340$ km/s) systems. The premaximum spectrum component is hardly discernable until April 26 in the strongest lines as a detail on the emission component at about -640 km/s.

The principal spectrum lines are about three times narrower than the lines of the premaximum spectrum on April 17. They belong to the same atoms as the premaximum ones. The diffuse-enhanced spectrum lines are broader and weaker than those of the principal spectrum. The diffuse-enhanced components of the neutral atom lines are either absent (FeI) or very weak (OI 6156 Å, OI 6158 Å, NaI 5889 Å, NaI 5895 Å). In the SrII resonance lines (4077 Å and 4215 Å) there are no diffuse-enhanced components. On the other hand, they

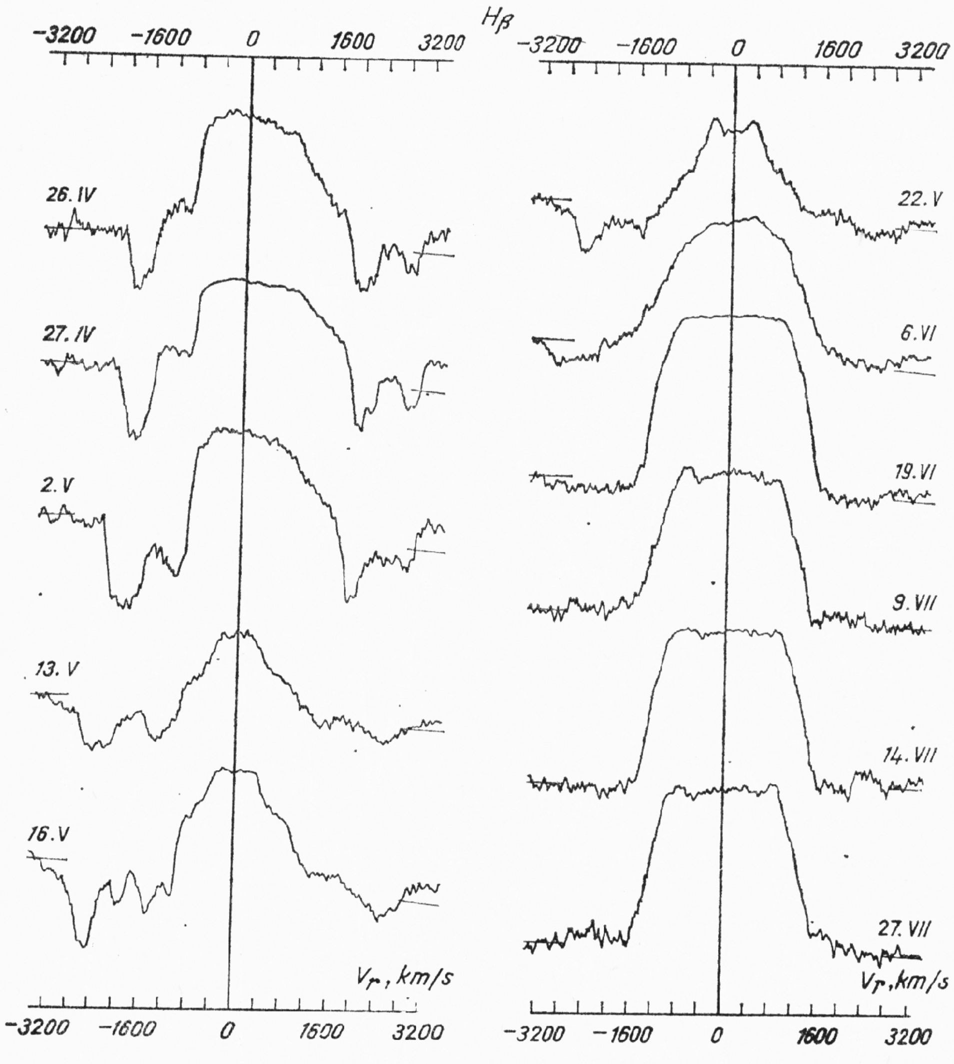

Fig. 2. Photographic darkening profiles of Hβ from the Crimean spectra (original dispersion 37 Å/mm)

are very intensive in the SiII lines (6347 Å and 6371 Å). Such a behaviour suggests that the region of line formation is strongly stratified and the lines of the diffuse-enhanced spectrum are formed in hotter gas than the ones of the principal spectrum.

Emission is definitely present in the lines of HI, SiII, OI (6156 Å and 6158 Å), NaI and all ionized metals.

April 19 and 20. The emission lines are enhanced. For HI and FeII they are stronger than the corresponding absorption components. The lines of both absorption systems have become sharper. In general the diffuse-enhanced components have strengthened, they are several times as intensive as the principal ones in the SiII lines, but in the SrII lines are still absent.

April 23 and 25. The diffuse-enhanced components of the hydrogen lines are already stronger than the principal spectrum components. But in the metal lines the principal components are still the stronger ones. The emission lines have become stronger and broader, the latter corresponding to the increased outflowing gas velocity. Till April 25 no forbidden lines have been recorded.

April 26 to May 2. The diffuse-enhanced components of the FeII and HI absorption lines are more intensive than the ones of the principal spectrum. In CaII K line the principal spectrum component is stronger. Evidently, the layer of diffuse-enhanced line formation is too hot for calcium to be only single-ionized. In general, the ionized metal lines weaken and only MgII 4481 Å diffuse-enhanced component is still intensive.

May 13. The nova already has an orion spectrum. The ionized metal absorption lines have practically disappeared. The diffuse-enhanced absorption compenents of the hydrogen lines are weak and the orion ones very intensive. They are broader than the diffuse-enhanced ones on the preceding spectra. Strong, very broad and structureless high-excitation lines of HeI (4026 Å, 4471 Å, 4921 Å), OII (4317—4319 Å, 4414—4416 Å), NII (near 4240 Å) have appeared in absorption. The corresponding emission lines are also very broad (e. g. it is impossible to resolve the band 4620-4700 Å into separate OII and NII lines).

May 16. The spectrum is the same in character as the above-described one. The orion absorption components have become narrower, but in the high-excitation lines they are still broad. That might be caused by the velocity dispersion effect which is more pronounced in the layers near the effective photosphere, and it is quite natural to consider OII and HeI lines of excitation energy greater than 20 eV as being formed deeper than the Balmer ones. Another possible explanation is the turbulence damping away from the star.

The emission component of H_β definitely shows a structure: it consists of a core of width ± 440 km/s and a broader component of half-width corresponding to the velocity of the gas producing the orion spectrum. This structure begins to show on May 13.

On the spectra taken on May 13 and 16 two more absorption components displaced to the violet ($V_r = -1050$ km/s and $V_r = -1900$ km/s) are clearly observable. On May 13 in the hydrogen lines the component of $V_r = -$ 1050 km/s is as strong as the principal spectrum component. In CaII K line this component is much weaker than the principal one. This suggests that the absorption in question is formed in hotter gas than the principal spectrum. On May 16 this component has strengthened in the Balmer lines. In the K line of ionized calcium it is sharp and intensive while the principal spectrum component is very weak.

May 22. The diffuse-enhanced absorption line system has faded out. The H_β emission structure has changed. In the line core (now of width ± 470 km/s) two symmetric peaks protrude at ± 325 km/s. On this spectrum a broad and strong absorption is seen on the short-wavelength side of H_δ. This may be the line SiIV 4088 Å, if its displacement corresponds to velocity about—3200 km/s. At the same time H_β has a faint absorption component corresponding to $V_r \approx -3100$ km/s. Probably it is formed in the layers near the effective photosphere where there is very little neutral hydrogen, but sufficient amount of SiIV (the third ionization energy of the silicium is >33 eV).

The intensity of the absorption component of the initial shift corresponding to velocity -1050 km/s has decreased in the Balmer lines, and its violet shift has increased. In CaII K line this component has disappeared and the principal spectrum component is still visible. Therefore, the gas in which it originates has a small mass and has become quickly transparent even in the resonance K line, because of its rarefying.

The changes of the H_β emission profile may be caused by the same gas. If it was ejected in conformity with the observed general regularities and has formed an equatorial ring and two polar blobs (Mustel, Boyarchuk, 1970), one could ascribe the observed emission peaks just to these blobs. On assuming the same gas velocity for the ring and the blobs, we estimate the inclination of the polar axis to the line of sight to be about 70°. An analogous estimate on the basis of the developed nebular spectrum line structure gives $i \sim 60°$ when $V = 1500$ km/s and the peaks are at ± 780 km/s (Bloch, 1969).

June 6. The emission lines have become broader and stronger. The band of OII and NII lines near 4620-4700 Å is very intensive. H_β has a weak absorption component limited at about —3100 km/s. Its emission has become again structureless.

June 19. Some greatly displaced faint absorptions have remained only in the high-excitation lines. A unidentified absorption feature has appeared at 4750-4770 Å. It might be ascribed to NII 4803 Å (in velocity limits from —3300 km/s to —2100 km/s), but we must notice that the line is not present in the emission.

The OII-NII emission band now extends from 4580 Å to 4720 Å, probably including also the lines CIII 4647 Å, CIII 4650 Å and HeI 4713 Å. The OIII forbidden lines at 5007 Å and 4363 Å are seen, but the line [OIII] 4959 Å is still absent.

On *July 9* LV Vul is already in the nebular stage. The continuum has faded out. The emission lines of OII and NII in the band 4620-4700 Å have disappeared, and the blend NIII 4634 Å, 4640 Å and 4641 Å is present. It is as intensive as H_β. Emission in HeII 4686 Å is also seen.

In the spectra taken on *July 14 and 27* the forbidden lines and HeII 4686 Å are stronger and stronger, but nevertheless, the blends NIII 4634 + 4640 + 4641 Å and H_γ + [OIII] 4363 Å surpass in intensity all other emission lines.

At the very beginning of the nebular stage the bright lines have no distinct structure as that was observed later.

The spectral evolution of LV Vulpeculae outburst is typical for the fast novae and any quantitative investigation of the available spectra would be representative of the phenomenon.

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Развитие спектра новой LV Лисички

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(Резюме)

По 27 спектрам прослеживается развитие спектра новой LV Лисички от предмаксимальной до небулярной стадии. По водородным линиям предмаксимального спектра 17 апреля 1968 г. установлено наличие градиента скорости расширения оболочки, а по линиям всех других атомов была определена практически одна и та же радиальная скорость —670 km/s. По скоростям, измеренным по абсорционным линиям, и структуре эмиссионной компоненты H_β оценено наклонение полярной оси Новой к лучу зрения $i \sim 70°$.

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