NOVA VULPECULAE 1984 N 2 IN 1985

By: Yu K. Bergner, A.S. Miroschnichenko, R.V. Yudin, N. Yu Yutanov, K.G. Dzakusheva, V.V. Ilyin, K.S. Kuratov, and D.B. Mukanov

Bergner, Yu.K., Miroshnichenko, A.S., Yudin, R.V., et al., 1988. *Astrophysics &Space Science*, 149, 63. Nova Vulpeculae 1984 N2 in 1985

Abstract:
The results of *UBVRHHK* photometric, *UBVRI* polarimetric, and spectrophotometric (2.1322.5-722.5 nm) observations of the second Nova Vulpeculae (QU Vul) are given for the period from May 1985 to December 1985. A dust shell of the Nova was discovered in June 1985. A model of the dust shell, to explain the observed properties of the Nova, is proposed. The paper reports *M,,, f ,* and the radius of the Nova for several times. Observations of QU Vul were launched with the 1 m telescope of the Assy High-Altitude Observatory (near Alma-Ata) in January 1985. The first results of *UBVRIJHK* photometry were published by Bergner *et al. (1985a*, b). Photometry of the Nova was performed 19 times over the period May 1985—December 1985 (Table I). The observations were made with the three-channel multipurpose photometer-polarimeter FP3U (Bergner *et al.*, 1985c, d). Nineteen Vul and 23 Vul (Table IV) served as comparison stars.

Article:

1. Photometric Observations

Figure 1 shows the visual light curve of the Nova, as plotted on the basis of our photometry and magnitude estimates in *L4U Circ.*, Nos. 4023-4026, 4033, 4059, 4108. The Nova has a gradual and slow light decrease after the maximum *(t,* 30-35d) which suggests that it belongs to the B a class (Duerbeck, 1981). From May 1985 to November 1985 the velocity of the light decrease of the Nova was very small in the *V* band (0".1005 day -1) and actually constant. Novae Dor 1971a and GQ Mus have similar light curves.

The observed IR-excess *(V - K* 2.m4) in January 1985 was caused by free-free emission of the expanding gaseous shell of the Nova and interstellar absorption. When there is no dust shell (V 1500 Cyg, GQ Mus), the excess decreases with time. In our case an increase of the excess began (Gehrz *et aL*, 1985), on the end of April and reached the maximum on the end of June (Figure 2). This suggests that the Nova formed a dust shell. However, no peculiarities connected with this process were observed in the light curve. This indicates either a small optical depth of the newly formed dust shell, or its non-sphericity or location of the dust layer beyond the line-of-sight. The dust temperature on the end of June, as estimated using IR indices corrected for free-free emission was 1500 K (Figure 5). The integral flux of its emission is (3.5 + 0.4) x 10 erg s cm '. Assuming its distance to be 1.16 + 0.02 kpc (Bergner *et aL*, 1985b) we calculated its luminosity *L,,* = (5.6 + 0.09) x 10' erg s '. The Novae luminosity was *L* = (1.5 + 0.2) x 1037 erg s -1 at that time. The ratio of the luminosity of the dust to that of the Nova yields the optical depth of the dust shell - 0.1.

2. Spectrophotometry

On the nights of 27 and 28 June, 1985 spectrophotometric observations of the Nova were made. The spectra were taken with the 1 m telescope of the Assy Observatory equipped with the Seia—Namioka spectrometer (Kalinenkov and Kharitonov, 1967). The aperture of the spectrometer is 2.5 nm. γ Lyr was used as a standard. Altogether 4 records of the spectrum were made in the range 322.5-722.5 nm. The obtained data were averaged. The averaged spectrum with the brightest identified lines is given in Figure 3. It is typical of a Nova at nebular phase. We estimated the contribution of emission lines to the observed fluxes in the *UBV* bands (Tereshchenko, 1977) using the energy distribution and *UBV* reaction curves (Straizhys, 1977). It proved to be $\Delta U = -1^m.1 \pm 0^m.1$, $\Delta B = -1^m.45 \pm 0^m.1$, $\Delta V = -1^m.1 \pm 0^m.1$.

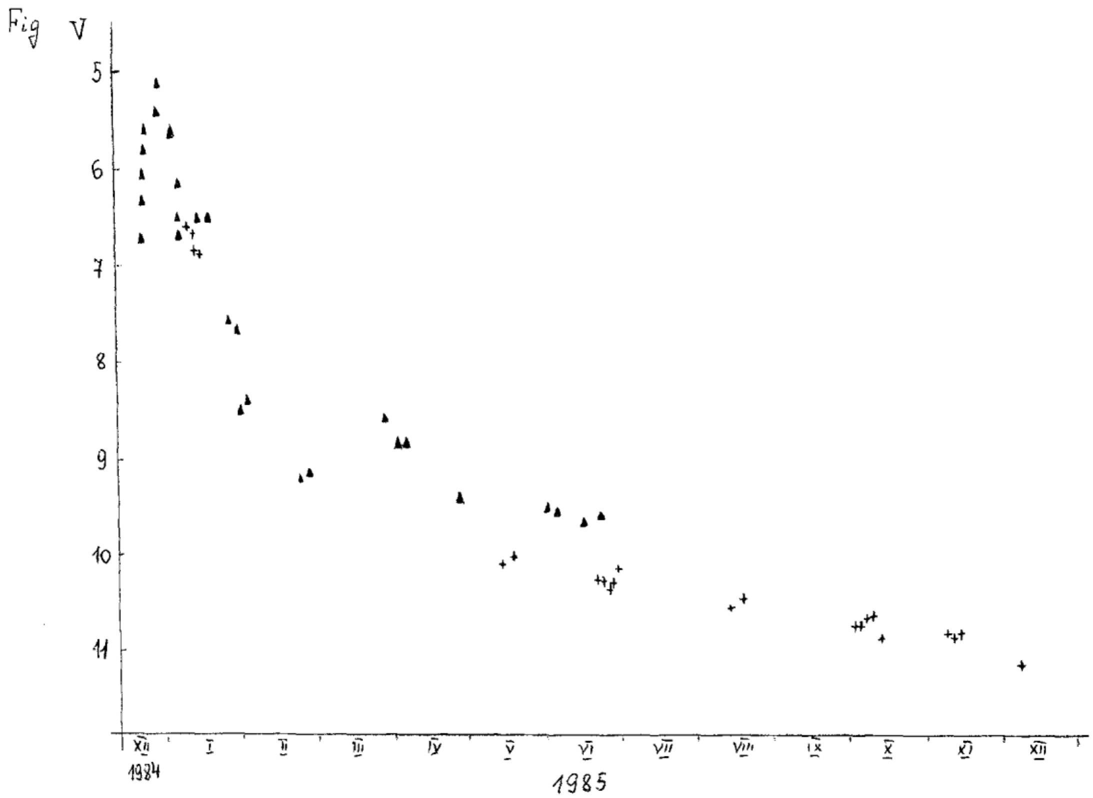

Fig. 1. Visual light curves for the Nova. △ visual magnitudes from *IAU Cir.*; + our observations.

TABLE 1

Photometry QU Vul in 1985. Observational errors in UBVRI are 0m.02, in JHK om.07.

J.D. 2446…	V	U-B	B-V	V-R	V-I	V-J	V-H	V-K
196.31	10.08	.0.70	0.32	2.15	2.45			
199.36	9.94	.0.80	0.35	2.04	2.30			
236.35	10.29	-0.96	.0.04	1.97	2.17			
240.32	10.30	0.01	0.01	2.03	2.16		2.70	3.20
241.40	10.31	-0.94	.0.07	1.99	2.16			
242.27	10.30	.0.97	-0.07	1.98	2.13	2.96	2.82	3.58
243.28	10.21	.0.92	-0.10	2.02	2.14			3.87
288.22	10.65	.1.03	.0.29	2.00	2.08			
290.22	10.44	.0.93	.0.20	1.83	1.91	3.20	3.10	3.57
339.15	10.82	.1.04	.0.34	1.81	1.74		3.00	
340.10	10.79	.1.03	-0.37	1.77	1.72			
340.14	10.80	-1.03	.0.37	1.78	1.74		2.95	3.06
342.15	10.73	.1.02	-0.33	1.71	1.75	3.22		
344.15	10.71	.1.02	.0.40	1.72	1.70			
347.17	10.90	.0.86	-0.48	1.97	1.85			
375.06	10.86	-0.93	-0.51	1.84	1.77	3.21		
376.08	10.91	.0.95	.0.53	1.63	1.68			
379.06	10.86	-1.04	-0.47	1.58	1.57	3.09		
404.03	11.17	.1.20	.0.63	1.84	1.82			

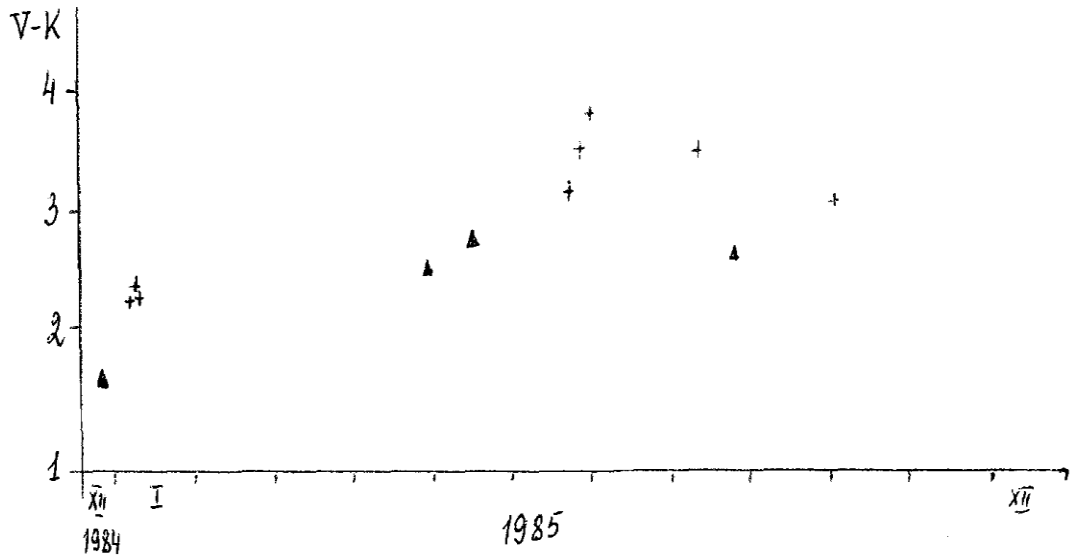

Fig. 2. Colour curve $(V-K)$. + our observations; △ other authors observations.

Hence, it follows that emission lines contribute better to the emission of the Nova at this phase than the continuum. The temperature of the Nova was determined by Zanstra's method using the intensities of Balmer lines. It attained 4 x 10^4 K. The radius of the star's photosphere and its integral luminosity was estimated using the latter value and energy distribution in the continuum according to the formula

$$\pi R_*^2 B_\lambda(T_*) \times 10^{-0.4A_\lambda} = D^2 E_\lambda \frac{L_*}{L_* + L_{sh}}, \quad (1)$$

where R_* and T_* are the radius and temperature of the star, respectively, B_λ is the Planck function; A_λ, the interstellar absorption at a wavelength λ; *D*, the distance to the Nova; E_λ, the emission intensity of the continuum at the wavelength λ; $L_* /(L_* + L_{sh})$, the ratio of the star's luminosity to that of the Nova (Boyarchuk *et al*, 1977). Physical parameters of the Nova are given for several time instants in Table II. They were calculated using $M_{v(max)}$ of the Nova computed previously (Bergner *et al.*, 1985b) and temperatures (Bergner *et al.*, 1985). Bolometric corrections for class I luminosity (Straizhys and Kurilene, 1981) were used in our calculation.

3. Polarimetric Observations

Eight estimates of the *UBVRI* emission polarization of the Nova were derived for 1985 (Table III). It seems to have emerged in the circumstellar shell of the Nova. The following factors are in favour of our point of view:

(a) Estimates of interstellar polarization in the vicinity of the Nova using three stars attained $P_m \approx 0.7\%$ and $\theta \approx 100°$, which differs from those observed on the Nova.

(b) Significant variability of both the degree and angle of the polarization indicates non-stationary processes in the regions of its emergence.

(c) The shape of the $P(\lambda)$ curve differs from that of the interstellar $P(\lambda)$ for all the time instants.

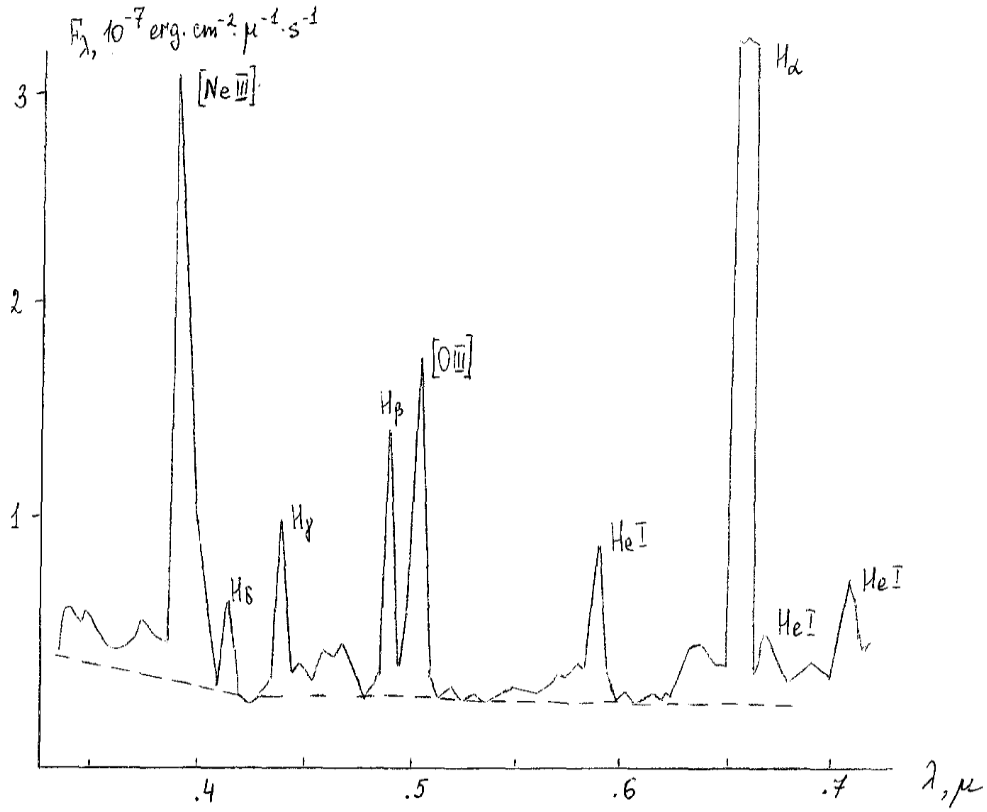

Fig. 3. Averaged spectrum of the Nova on June 27–29, 1985.

TABLE II

Physical parameters of the Nova

	V	M_v	T_* (K)	BC	$M_{\rm bol}$	R (cm)
23.18/12/84	5.8	−6.0	1×10^4	−0.3	1.02×10^{38}	3.8×10^{12}
25.5/12/84	5.4	−6.4	7×10^3	0.1	1.02×10^{38}	7.5×10^{12}
27–29/06/85	10.3	−0.5	4×10^4	−3.7	1.45×10^{37}	9×10^{10}

TABLE III

Polarimetric observations of the Nova

J.D.	U		B		V		R		I	
	p (%)	θ (°)	p (%)	θ (°)	p (%)	θ (°)	p (%)	θ (°)	p (%)	θ (°)
2446075.07	1.6 ∓ 0.2	164 ∓ 4								
2446196.31	3.1 ∓ 1.1	156 ∓ 10	2.9 ∓ 0.2	137 ∓ 2	1.8 ∓ 0.3	130 ∓ 5				
2446240.32					0.8 ∓ 0.5	124 ∓ 18	0.7 ∓ 0.2	152 ∓ 8		
2446242.27	1.7 ∓ 0.8	129 ∓ 13	0.9 ∓ 0.3	120 ∓ 10			0.4 ∓ 0.2	179 ∓ 14		
2446243.28	3.0 ∓ 1.0	110 ∓ 10	1.7 ∓ 0.3	121 ∓ 5	0.9 ∓ 0.4	24 ∓ 12	1.2 ∓ 0.2	131 ∓ 5	1.1 ∓ 0.8	116 ∓ 21
2446339.15	2.6 ∓ 1.0	180 ∓ 12	1.2 ∓ 0.4	140 ∓ 9	2.5 ∓ 0.8	162 ∓ 10	1.3 ∓ 0.2	150 ∓ 4		
2446340.10	0.7 ∓ 1.0	173 ∓ 30	1.3 ∓ 0.5	154 ∓ 11	0.7 ∓ 1.0	134 ∓ 48	1.5 ∓ 0.2	146 ∓ 4		
2446342.15	0.9 ∓ 0.7	121 ∓ 20	0.9 ∓ 0.4	156 ∓ 13	1.2 ∓ 0.5	112 ∓ 12	0.7 ∓ 0.2	160 ∓ 6	1.2 ∓ 0.8	154 ∓ 19

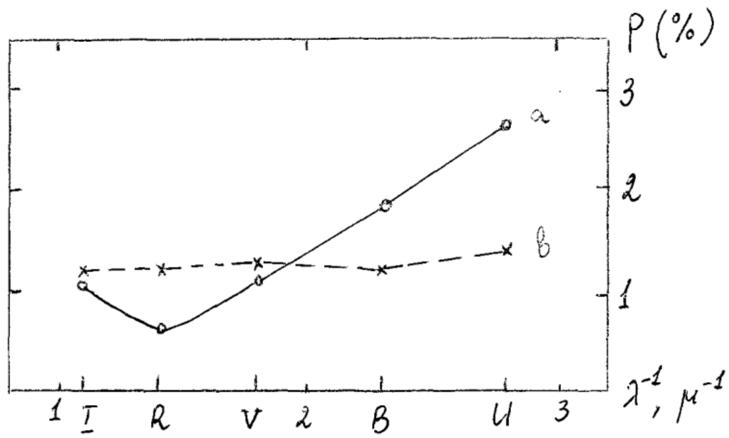

Fig. 4. Wave dependence of the polarization degree of the Nova. (a) May, June; (b) October 1985.

Figure 4 shows an averaged wave dependence of the intrinsic polarization degree of the Nova for two observational periods. The 'a' curve corresponds to the period of formation of the dust shell (May—June). The `b' curve shows the *P(λ)* dependence four months after the completion of the process (October). Although the accuracy of measurements of the polarization in the blue part of the spectrum was not very high, however, one could note a tendency to an increase of the polarization degree with a decrease of the wavelength. Such a behaviour of *P(λ)* may be explained by the presence of small silicate grains in the shell (Zenner and Serkowski, 1972). Silicate and graphite are the most probable materials of dust shells for Novae (Gehrz *et al.,* 1980; Ney and Hartfield, 1978). It should be noted that Gehrz *et al.* (1986) discovered 10 and 20 micron silicate emission features as early as May 1985. This is a direct evidence in favour of the silicate presence in the Novae shell. One can make a conclusion on the basis of the *P(λ)* shape and in accordance with Zellner and Serkowski (1972) that the silicate particles do not exceed 0.07μ.

TABLE IV

Photometry of comparison stars. Photometry of 19 Vul was obtained by the authors (observational errors of observations in all filters do not exceed $0^m.04$), 23 Vul, sée Bergner *et al.* (1985).

Star	BS	*V*	*U* – *B*	*B* – *V*	*V* – *R*	*V* – *I*	*V* – *J*	*V* – *H*	*V* – *K*
19 Vul	7718	5.52	1.46	1.39	0.98	1.70	2.28	3.02	3.11
23 Vul	7744	4.52	1.11	1.26	0.96	1.67	2.15	2.88	3.00

The change of the *P(λ)* shape in the second observational period seems to be connected with a decrease of the optical thickness in the UV range and with a possible increase of the size of dust grains (Zellner and Serkowski, 1972).

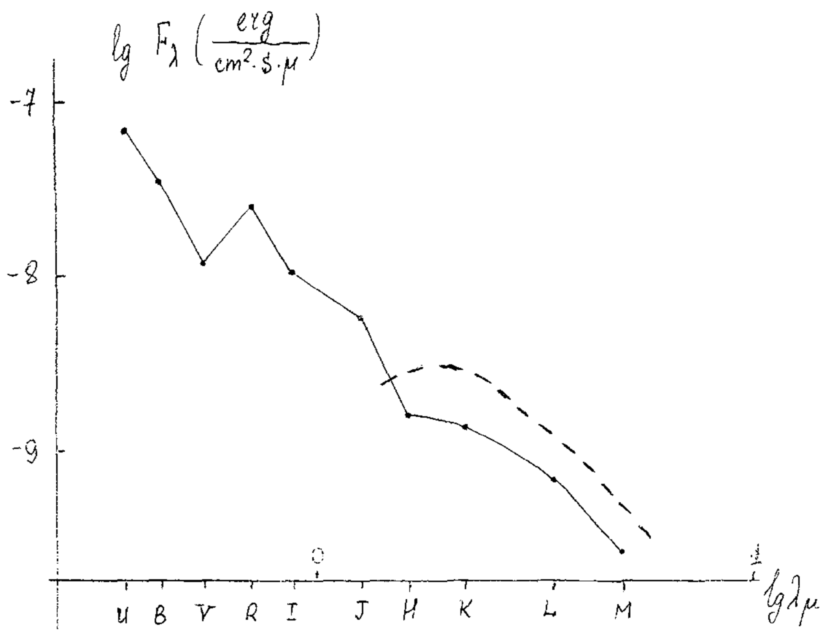

Fig. 5.

4. Dust Shell of the Nova

In accordance with Mustel and Boyarchuk's (1970) model, a gaseous shell lost by the Nova is an equatorial disk with two polar caps. An outflow of carbon nucleation seeds took place during the loss of the gaseous shell (Draine, 1979). Thus, we suspect that the dust shell does not have any spherical symmetry either and its main mass is concentrated on the disk. The observed rate of intrinsic polarization (about 2%) may be due to a shell in a form of a geometrically thick but optically thin dust disc, located in the plane, containing the line-of-sight. The parameters of the shell can be derived from system of equations for emission polarization of a geometrically thick disk (Dolginov *et aL*, 1979) and the energy balance of the dust shell

$$p = \tfrac{3}{32}\pi\,|b_1|\,\tau \sin^2\theta\,,$$
$$\frac{L_{\rm IR}}{L_*} = y(1 - e^{-\tau})\,, \qquad (2)$$
$$\tau = \pi a^2 n_d Q_{\rm abs} l\,;$$

where p is the polarization degree of the Nova emission; τ and l, optical and geometric thicknesses in the disk's plane, respectively; θ, an inclination angle of the disk referred to the line-of-sight; Q_{abs}, an effective cross section of dust absorption; n_d, the mean concentration of grains on the disk; a, the average size of a dust grain; and y is the ratio of the volume of the disk to that of the sphere with the same radius; $|b_1| = 1$.

We use the additional relations

$$R = vt\,,$$
$$L_* = 16\pi\sigma\overline{Q}_{\rm IR} T_d^4 R^2\,, \qquad (3)$$
$$\overline{Q}_{\rm IR} = 3.22a\left[\frac{T_d}{10}\right]^{1.65},$$
$$M = \tfrac{16}{3}\pi a \tau y \rho R^2\,,$$

where v is the mean velocity of the shell's expansion of the Nova (680 km s^{-1}); the mean Planck cross-section of grain absorption; *p* and T_d, their density and temperature, respectively; and *t*, the time span from the start of the flare.

Assuming that $Q_{abs} = 1$, $\theta = 90°$, n_d = const., $l < 0.2R$, $p = 3$ g cm^{-1}, we derived the following parameters of the shell: $\tau = 0.1$, y = 0.4, $R = 1.1 \times 10^{15}$ *cm*, $a = 2 \times 10^{-6}$ cm, $M = 4.25 \times 10^{24}$ g, $n_d > 3.7 \times 10^{-5}$ cm.

Then the dust shell expands due to the pressure of emission and the matter outflow from the Nova. Anomalously large emission outflows in the *J* filter seem to indicate a powerful emission in the P_β line (1.2 mkm) (Simon *et al.*, 1983). In particular, this line was observed in the Nova V693 Cr A (Catchpole *et al.*, 1985). As a result of the expansion of the shell its optical thickness decrease with time, which caused decreases in the polarization degree and in the IR radiation of the Nova.

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