PART II

CATACLYSMIC VARIABLES

OPTICAL OBSERVATIONS OF RECENT NOVAE

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Abstract:

The observations of two rather different classical novae, V 1500 Cyg (= Nova Cyg 1975) and NQ Vul (= Nova Vul 1976), are presented and compared. Nova Cyg 1975 is outstanding with respect to absolute magnitude ($M = -10$), range of brightening($\Delta m = 19$), and speed of evolution ($t_3 = 3.6$ days). Its prenova object had to be fainter than about magnitude 9. The corresponding values for Nova Vul 1976 are rather conservative ($M \approx -7.5, \Delta m \approx 12, t_3 = 40$ days, absolute magnitude of the prenova ≈ 4.5). The light curve of Nova Cyg 1975 is very smooth. Some superimposed photometric variations of a small and slightly variable amplitude of a period of 3.4 hours are most naturally ascribed to a binary nature of Nova Cyg 1975. Nova Vul 1976 has a completely different lightcurve with extremely strong rapid irregular variations of considerably amplitude. There is a remarkable second maximum about 14 days after discovery.

The spectroscopic evolution of Nova Cyg 1975 was very fast. The nebular stage was already reached 9 days after maximum. Whereas the high velocity absorption systems were almost negligible in Nova Cyg 1975 (but note that the diffuse enhanced absorption system was clearly identified on Sept. 1.1 UT, 1975), these systems were prominent in Nova Vul 1976.

No significant dust formation occurred in the shell of Nova Cyg 1975 during its evolution. But IR observations showed that considerable dust condensation took place in the shell of Nova Vul 1976 about two months after discovery.
The ejected mass of Nova Cyg 1975 was estimated to be about 10^{-5} solar masses.

Introductory Remark

The term nova comprises several categories (classical novae, recurrent novae, novalike variables), which are also subsumed under the term cataclysmic variables. I shall confine myself to classical novae and report about observations of two rather different recent novae, namely Nova Cyg 1975 (= V 1500 Cyg) and Nova Vul 1976 (= NQ Vul).

I. Nova Cyg 1975 (V 1500 Cyg)

1. Introduction:

Nova Cyg 1975 was outstanding in several respects. It was the most luminous galactic nova ever observed (absolute visual magnitude at maximum about -10) with the largest range of brightening (more than 19 magnitudes), and the fastest evolution (3 magnitudes within 3.6 days). The preoutburst object of Nova Cyg 1975 which was not found on the Palomar Sky survey, is also exceptional. Its luminosity must have been very low with an absolute magnitude, fainter than +9. Nova Cyg 1975 was also very bright at maximum in apparent magnitude ($V_{max} = 1^{m}.8$) and was discovered well before maximum. Therefore Nova Cyg 1975 is the best observed nova, especially with respect to spectral coverage during a great part of the light curve. Of special interest are the IR observations which, in connection with the optical observations, allow interesting conclusions about the outburst mechanism.

2. Spectral Evolution

The early phases of the spectral evolution of Nova Cygni 1975 have been described by several authors (c.f.e.g. Woszczyk et al. [1975] , Tomkin et al. [1976] , Andrillat [1977] , Boyarchuk et al. [1977] , Duerbeck and Wolf [1977]).

Figure 1 shows intensity tracings of blue ($3850 \lesssim \lambda \lesssim 5000$ Å) and red ($5700 \lesssim \lambda \lesssim 6700$ Å) spectrograms (12 Å/mm) taken during three consecutive nights (Aug. 30.1, Aug. 31.1 and Sept. 1.1 UT, 1975) around the maximum of Nova Cyg 1975 which occurred on Aug.30.9. UT (Duerbeck and Wolf, 1977).

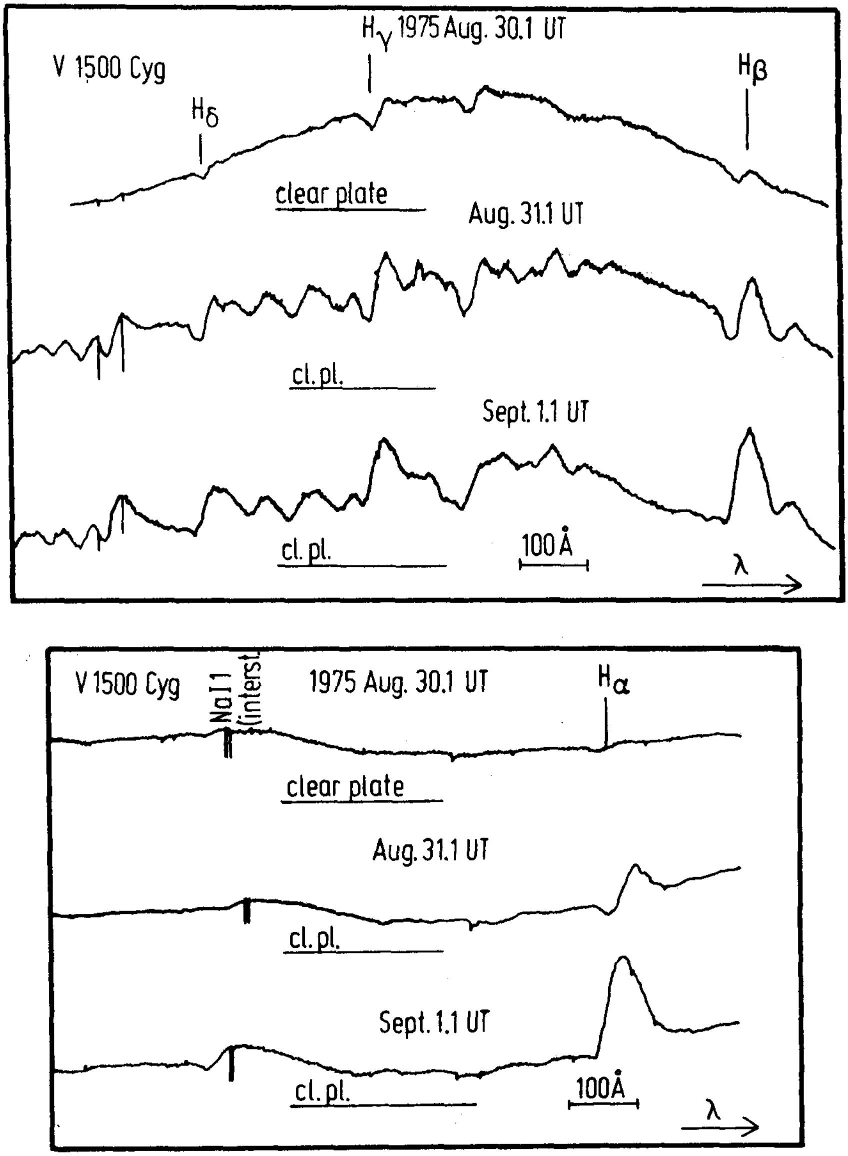

Fig. 1 Intensity tracings of blue and red spectrograms of Nova Cyg 1975, taken around maximum light.

The pre-maximum spectrum is characterized by broad blueshifted absorption lines of the Balmer sequence and of ionized metallic lines (especially FeII-lines). Some very weak emission of the Balmer lines is already discernible on Aug. 30.1. The P-Cygni emission is growing rapidly in intensity during the subsequent two nights. Sharp interstellar absorption lines of CaII H and K and NaD_1 and NaD_2 are prominent.

In Fig. 2 tracings of blue spectrograms (28 Å/mm; 3700 $\lesssim \lambda \lesssim$ 5000 Å) are presented, which show the very rapid spectral evolution of Nova Cyg 1975 from the pre-maximum stage through the nebular stage (Woszczyk et al. 1975).

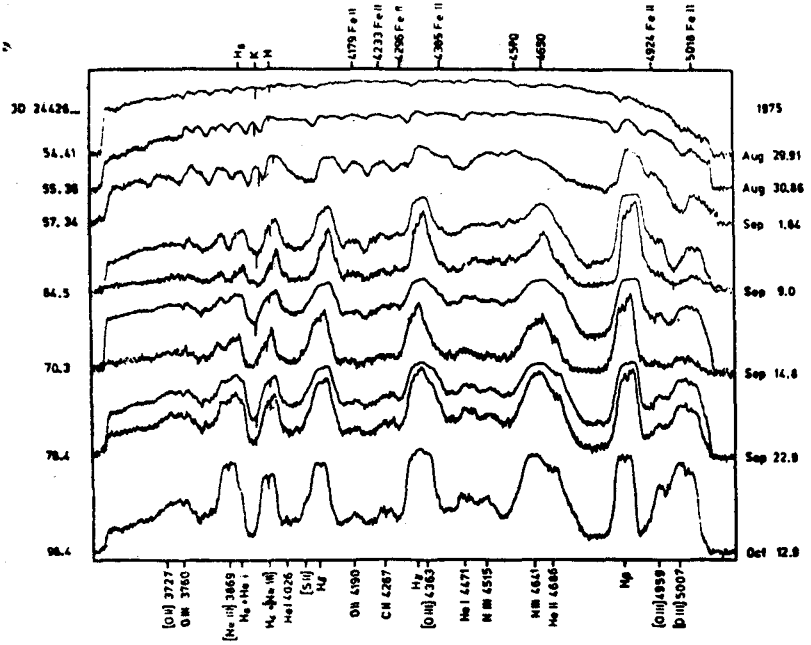

Fig. 2: The spectral evolution of Nova Cyg 1975 between Aug. 29.9 and Oct. 12.8 UT, 1975 (Woszczyk et al. 1975).

From Sept. 3 to 5 the He emission lines at λλ 3888, 4471, and 4686 and N III λ 4641 appeared. The first features of the nebular stage (forbidden lines of [O III] and [Ne III] emerged as early as Sept. 8, which is only 9 days after maximum (normally these lines appear 30 or 40 days after maximum in fast novae).

It has been stated several times in the literature that Nova Cyg 1975 has not developed any high velocity absorption systems. But the diffuse enhanced absorption system is clearly present on our spectrograms from Sept. 1.1 UT (c.f. intensity tracings of H_α to H_δ of Fig. 3) and is already indicated on Aug. 31.1, i.e. only eight hours after maximum.

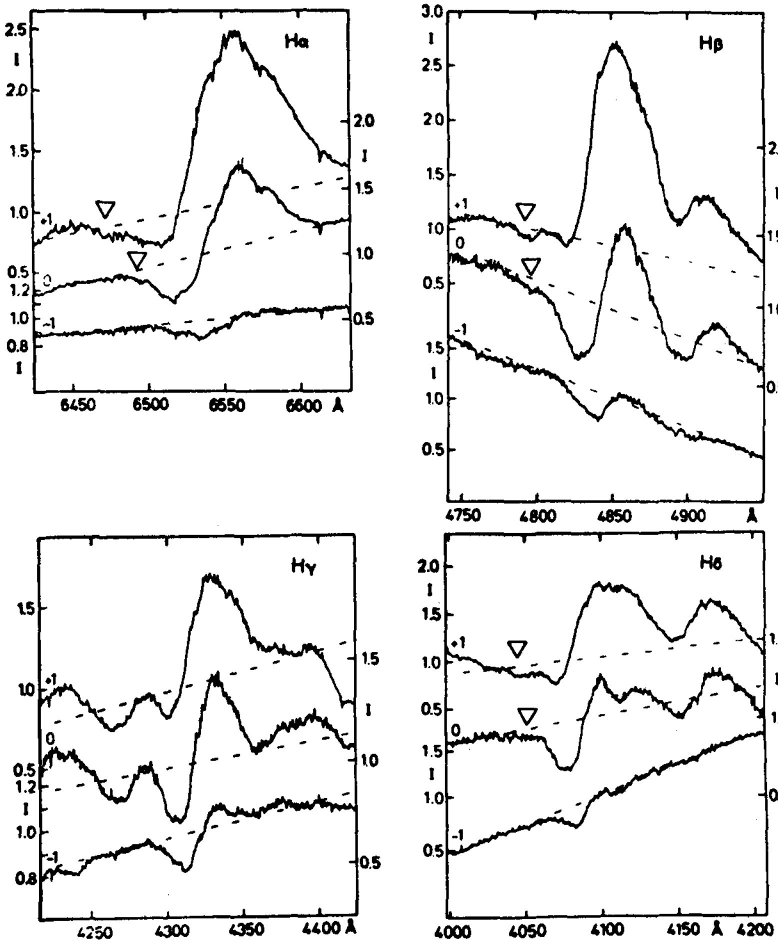

Fig. 3: Intensity tracings of the Balmer lines (H_α to H_δ) of Nova Cyg 1975 for Aug. 30.1 (-1), Aug. 31.1 (0), and Sept. 1.1 (+1) UT, 1975. The dashed lines represent the coarse of the continuum. Note that the intensity scale is different for the various tracings as indicated on the various ordinates. The diffuse enhanced absorption component is marked with arrows (Duerbeck and Wolf 1977).

Some structure in the emission components of the hydrogen lines is discernible already on Aug. 31.1 with velocity components of -740, -60, and +620 km s^{-1}. This structure is more pronounced on the spectrograms of Sept. 1.1 with the corresponding velocity components of -930, -350, and +450 km s^{-1}. The different components varied in intensity in a different way. Schömbs and Spannagl (1976) found that the asymmetry of the emission of H_α and H_β changed. Until Sept. 3 the blue wing was enhanced; from Sept. 10 on the red wing was stronger. This change in inclination must have occurred just around Sept. 4 and Sept. 5 as can be inferred from the intensity tracings of H_γ and H_δ of high dispersion spectrograms taken at HPO (Fehrenbach and Andrillat 1976) and from H_α scans (resolution 1.3 Å; see Fig. 4) of Tomkin et al. (1976).

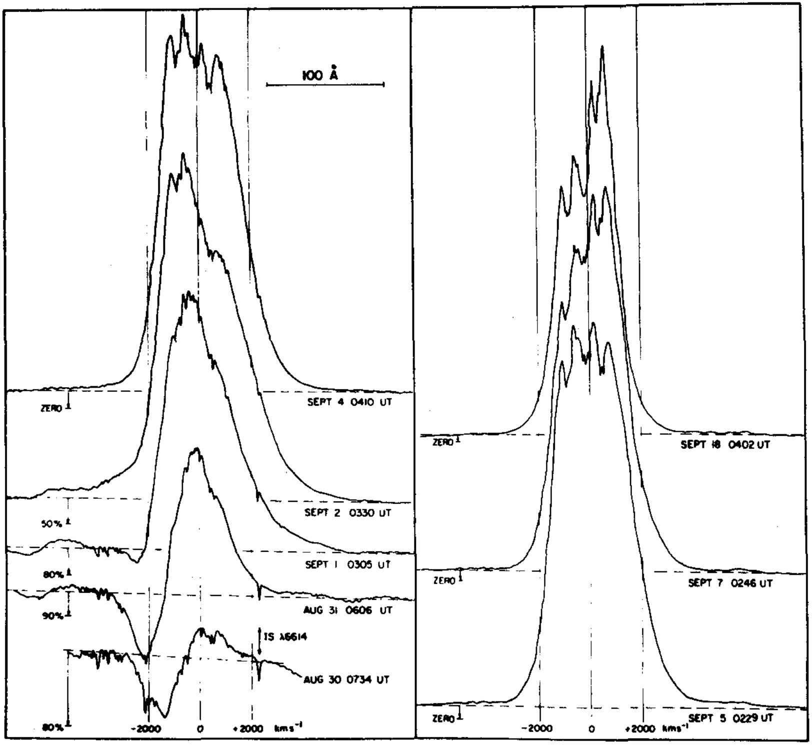

Fig. 4: Scans of H_α of Nova Cyg 1975. A several component structure in the emission is already present at the very early stages of the spectral evolution. Note the change of the relative intensities of the four emission components (Tomkin et al. 1976).

Near-infrared spectroscopic observations made at the Steward Observatory (Strittmatter et al. 1977) are of special interest with regard to the behaviour of the OI lines in relation to the Balmerlines. Although most OI lines remained relatively weak, the line OI λ 8446 (OI λ 11287 behaved similarly) was comparable with H_α throughout much of September and October, but declined in relative intensity by an order of magnitude by December 1975. The authors explain the unusual strength of OI $\lambda\lambda$ 8446, 11287 compared to the other OI lines and their persistence as due to strong L_β fluorescence in clouds with high H_α optical depth. From the similarity of the profiles of H_α and OI (Fig. 5), it is concluded that there were at least four such clouds.

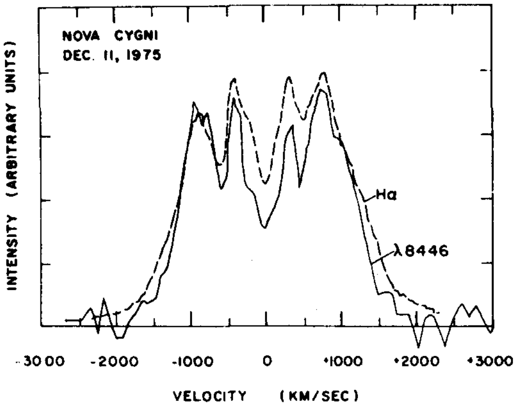

Fig. 5: Emission line profile of H_α and of the OI 8446 line (Strittmatter et al. 1977).

Infrared coronal lines (Grasdalen and Joyce, 1976) and red and near infrared coronal lines (Fehrenbach and Andrillat, 1976, Ferland et al. 1977) have been identified in the spectrum 35 days after outburst. Some of these lines (e.g. [Fe X] line) maintained their intensity during 20 to 30 days. The occurence of such coronal lines demands a model in which parts of the ejected clouds contain a hot shocked low density gas of a temperature of about 10^6 K.

3. Radial Velocities

The radial velocities for the different components of the Balmer emission- and absorption lines as determined from our spectrograms taken around maximum light of Nova Cyg 1975 are given in Table 1.

Table 1: Radial velocities of the Balmer lines
(a = absorption, e = emission component)

J.D.	line	a1	a2	e1	e2	e3
2442654.7	H_α	-2100:	-1320		+ 30	+820:
(Aug.30.2 UT)	H_β		-1380		-200	
	H_γ	-1870:	-1350		+ 60	
	H_δ		-1360		-130	
	H_ε		-1590			
	H 8		-1380			
2442655.6	H_α	-3120	-2200	- 790	-100	+610
(Aug.31.1 UT)	H_β	-3760:	-1940	- 730	- 70	+600
	H_γ		-1770	- 690	+ 20	+660
	H_δ	-3460:	-1920		-110	
	H_ε		-1730		- 70	
	H 8		-1490			
	H 9		-1570			
	H10		-1590			
	H11					
	H12		-1600			
2442656.6	H_α	-4060	-2520	- 920	-290	+540
(Sept.1.1 UT)	H_β	-4060	-2550	-1050	-500	+320
	H_γ	-4110	-2200	- 900	-130	+730
	H_δ	-3920	-2220	- 860	-320	+230
	H_ε		-2050	- 900	-450	
	H 8		-1830	- 960	-420	-160
	H 9					
	H10		-1650			
	H11					
	H12		-1560			

Similar values were found by others (c.f.e.g. Woszczyk et al. 1975, Tomkin et al. 1976). The mean radial velocity of the strongest component (a2) is -1400 ± 40 km s^{-1} on Aug. 30.1.; on Aug. 31.1. the strongest component has a displacement of -1750 ± 80 km s^{-1}, and on Sept. 1.1 UT the velocity of the main component is-2070 ± 130 km s^{-1}. However, the absorption components get more and more filled in by the undisplaced emission of increasing strength. As a consequence of the Balmer decrement this effect is particularly strong at lower Balmer-lines and decreases with increasing quantum number n (Fig. 6).

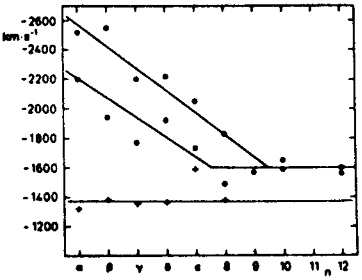

Fig. 6: Influence of the emission on the measured Doppler displacements of the Balmer absorption lines. + 0 ● denote the measurements from the spectrograms of Aug. 30.1, Aug. 31.1, and Sept. 1.1 UT, 1975 respectively.

For quantum number n ≥ 10, more or less constant velocities of about -1600 km/s were found in Aug. 31.1 UT and Sept. 1.1 UT. The velocities determined from the pre-maximum spectrum (Aug. 30.1 UT) and from the principal spectrum (Aug. 31.1 and Sept. 1.1) therefore differ only by about 200 km s^{-1}. The corresponding velocity of the diffuse enhanced spectrum is -4050 ± 50 km s^{-1}.

No systematic differences were found between the radial velocities of the Balmer lines and metallic lines of different ionization and excitation potentials (Duerbeck and Wolf 1977).

4. The Interstellar Lines and the Distance

Several interstellar lines are clearly visible in Nova Cyg 1975. The radial velocities which we determined from our spectrograms are listed in Table 2.

Table 2: The radial velocities of the interstellar lines.

Ca II	3933	- 8.1 ± 0.4 km s^{-1}	(14 spectrograms)
Ca II	3967	- 9.3 ± 0.5 km s^{-1}	(14)
Ca I	4227	-14.9 ± 2.0 km s^{-1}	(12)
CH^+	4233	-10.8 ± 1.2 km s^{-1}	(13)
Na I	5890	- 9.3 ± 0.2 km s^{-1}	(11)
Na I	5896	- 9.5 ± 0.3 km s^{-1}	(11)

The weighted mean of the velocities is -9.5 km s^{-1} and is in good agreement with the values given by Tomkin et al. (1976). They scanned the interstellar lines with resolutions from 0.03 Å to 0.10 Å. The profiles of Ca II H, Na I and K 1 are shown in Fig. 7.

Whereas the Na I D_2 line (λ 5890) shows an almost rectangular profile, the KIλ7699 line is nicely structured. Tomkin et al. 1976 found that the KI λ 7699 line structure corresponds closely with that of the nearby star 55 Cyg and they conclude that Nova Cyg must be somewhat more distant than this star. From the equivalent widths of Ca II K (W_λ = 0.30 Å) and the Na I D lines (W_λ = 0.69 Å) and using the relations of Hobbs (1974) and Binnendijk (1952) we found a distanceof r = 1.4 ± 0.2 kpc.
On the basis of infrared observations Gallagher and Ney (1976) and Ennis et al. (1977) determined a blackbody expansion parallax of $1.2 \leq r \leq 2.3$ kpc corresponding to a velocity range from 1300 to 2500 km s^{-1}. Table 3 contains distance determinations from several authors using different methods. The average from this table is r = 1.4 kpc.

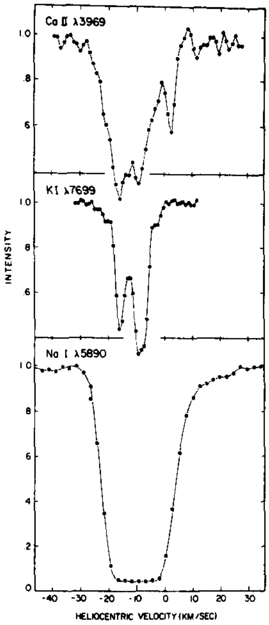

Fig. 7: The profiles of the interstellar lines (Tomkin et al. 1976).

Table 3: Distance of Nova Cyg 1975

a) From interstellar lines

$r = 1.4 \pm 0.2$ kpc (Duerbeck and Wolf, 1976)
$r = 1.0 \pm 0.3$ kpc (Tomkin et al., 1976)

b) From infrared observations (blackbody expansion parallax)

$1.2 \leq r \leq 2.5$ kpc (Gallagher and Ney, 1976)
$1.3 \leq r \leq 2.5$ kpc (Ennis et al., 1977)

for $1300 \leq v \leq 2500$ km/s
$r = 1.6$ ($v = 1600$ km/s)

c) From the lightcurve

$r = 1.4$ kpc (Young et al., 1976)

5. Lightcurve and Bolometric Luminosity

From the visual lightcurve of Fig. 8 (Young et al., 1976) the time and the apparent visual magnitude of the maximum were determined to t_0 = Aug. 30.88 (UT), 1975 and $m_v = 1.85$. The lightcurve illustrates the extremely fast evolution of $t_3 = 3.6 \pm 0.1$ days.

The maximum of the lightcurve is not reached at the same time for all wavelengths. Infrared observations (Gallagher and Ney 1976, Ennis et al. 1977) show that the maximum is reached at progressively later epochs with increasing wavelength. From Table 1 of the paper of Ennis et al. (1977) it is evident that around 10 μ the maximum is reached as late as Sept. 2, 1975. Wamsteker (1977) obtains the empirical relation: Epoch of maximum light = 31.31 Aug. 1975 UT + 0.68 ln λ (μm), by combining

Table 4: K, L, N magnitudes of Nova Cyg 1975 (Wamsteker, 1977)

U.T. (1975)	K(2.2 μm)	L(3.6 μm)	N(10.6 μm)
Aug. 30.16		+1.12	+1.04
Aug. 31.18	+0.55	+0.05	-0.20
Sept. 01.16	+0.18	-0.46	-0.82
Error estimate	ε ±0.08	±0.10	±0.75

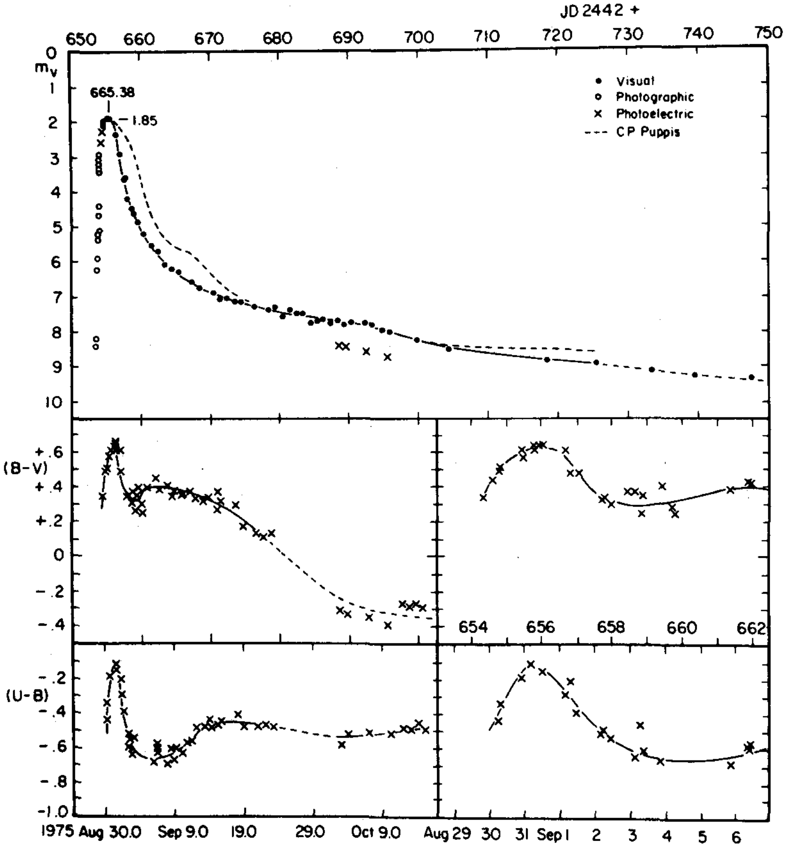

Fig. 8: Lightcurve of Nova Cyg 1975 (Young et al., 1976)

his infrared observations (see Table 4) with the R and I observations of Thé (1976) and with Gallagher and Ney's (1976) observations.

A possible explanation of this behaviour is the assumption that in the infrared the expanding shell remained optically thick until Sept. 2, 1975 (blackbody stage) and that the wavelength dependence of the epoch of maximum light is due to a decrease with time of the temperature of the expanding shell. The transition from blackbody to thermal bremsstrahlung emission can be seen from Fig. 9 (Ennis et al., 1977).

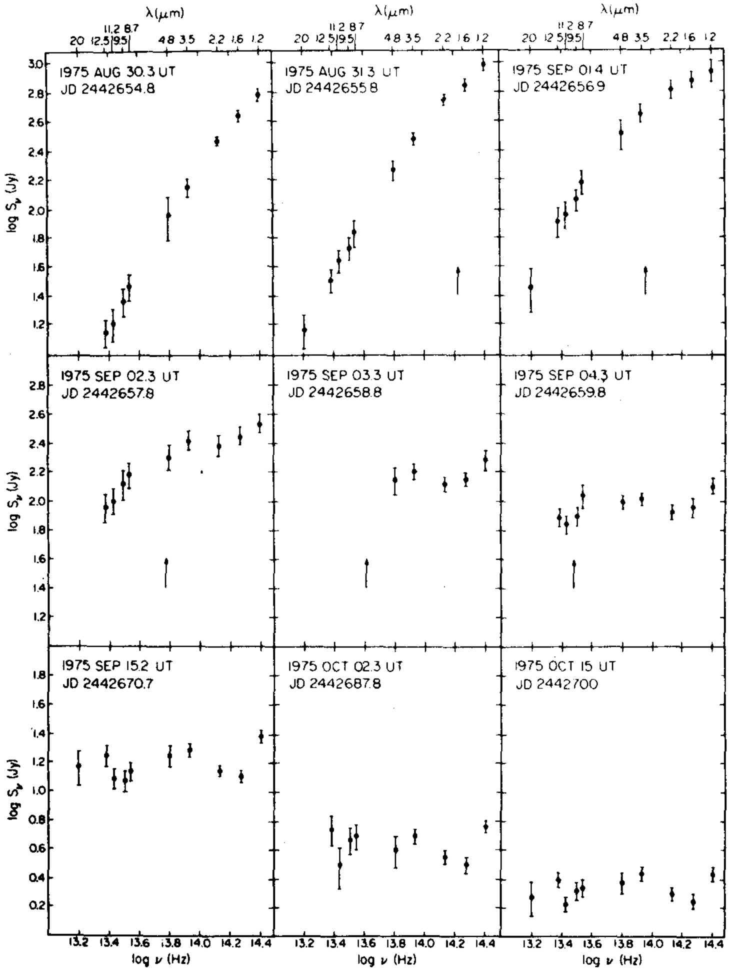

Fig. 9: Infrared observations of Nova Cyg 1975. The transition from blackbody to thermal bremsstrahlung emission occurred on Sept. 2, 1975 (Ennis et al., 1977).

About 300 days after the explosion Ennis et al. (1977) observed also some long wavelength (10μ) emission (Fig. 10) which may be related to the formation of dust grains. But unlike to FH Ser (1970) Nova Cyg 1975 has certainly not formed a thick dust shell of any significance for the energy balance.

Gallagher (1976) argues therefor that ionization of the gas generally prevents grain condensation in very luminous novae. Also unlike to FH Ser, constant luminosity was <u>not</u> maintained for the first 100 days in Nova Cyg 1975. On the basis of satellite UV observations from the ANS (Astronomical Netherlands Satellite) Wu and Kester (1977) found a decrease of the bolometric luminosity by a factor of 20 within 100 days from maximum. Early Copernicus satellite UV observations (Jenkins et al., 1977) from Sept. 1 to Sept. 9, 1975 have already shown that the continuum flux in the UV decreased as the nova evolved.

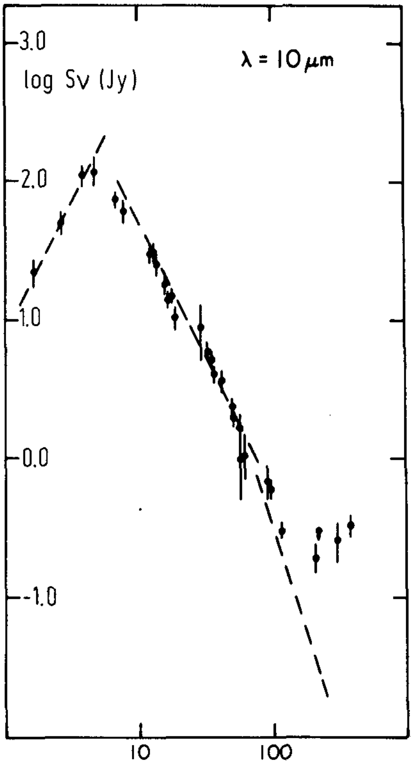

Fig. 10: The time dependence of the infrared emission at 10μ . Abscissa is t (days after outburst). Some increase in emission which may be related to the formation of dust grains occurred about 300 days after the explosion (Ennis et al., 1977).

This has some theoretical implications. According to the thermonuclear runaway model of a nova outburst (c.f. Starrfield, Sparks, and Truran, 1976 and references therein) it is likely that after the runaway the white dwarf becomes a relatively stable shell burning star with a large radius and a high temperature. As a consequence an extended period of high constant bolometric luminosity is expected, following the initial outburst (Gallagher and Starrfield, 1976). Such a behaviour was supposed to be common to all classical novae, regardless of speed classes. The observations of Nova Cyg 1975 described above are obviously not in agreement with this prediction.

6. Absolute Magnitude at Maximum, Date of Onset of Explosion, Prediscovery Observations.

The interstellar absorption of the part of the galaxy where Nov Cyg appeared, has been investigated by Hartl (1976). From his data Duerbeck and Wolf (1977) estimate $E_{B-V} = 0.29$ for Nova Cyg 1975. A similar value ($E_{B-V} = 0.35$) was derived by Young et al. (1976) whereas Schild (1976) suggests $E_{B-V} = 0.12$ mag. Using $E_{B-V} = 0.29$, the intrinsic magnitude and colours around maximum of Table 5 have been determined. Also included in Table 5 are the temperatures of the nova around maximum. T_V are blackbody temperatures derived from $(B-V)_o$ and $(U-B)_o$ indices. The blackbody temperatures T_{ir} are those derived by Gallagher and Ney (1976) from infrared observations.

Table 5: Intrinsic colours and temperature around maximum

Date (UT)	V	B-V	U-B	V_o	$(B-V)_o$	$(U-B)_o$	T_V	T_{ir}
1975 Aug. 30.2	2.04	0.50	-0.40	1.15	0.20	-0.60	9000	8500
Aug. 31.1	1.85	0.65	-0.10	0.95	0.35	-0.30	7000	6500
Sept. 1.1	2.40	0.60	-0.25	1.50	0.30	-0.45	8000:	5500

With $V_o = 0.95$ and the distance $r = 1.4$ kpc the absolute magnitude of Nova Cyg 1975 at maximum comes out to be $M_V = -9.8 \pm 0.3$ corresponding to a luminosity of $L = 700\,000\ L_\odot$. Thus Nova Cyg 1975 is the intrinsically most luminous galactic Nova ever observed (usual M values for fast novae are ranging from -6 to -8). As no object at the position of Nova Cyg 1975 was found on the Palomar Sky Survey prints (de Vegt et al., 1975; Beardsley et al., 1975) the brightening was at least 19 mag. As mentioned before, this is the largest brightening ever observed (normal values for fast novae are 8 - 12 magnitudes). Using Schmidt-Kaler's (1957) empirical relation between absolute visual magnitude at maximum, M_V(max) and the time of decline through 3 magnitudes, t_3,

$$M_V(\mathrm{max}) = -11.5 + 2.5 \log t_3,$$

we obtain with $t_3 = 3.6 + 0.1$ days;

$$M_V(\mathrm{max}) = -10.1$$

Assuming $T = 7000$ K (temp. at maximum), B.C. = 0 and $L = 700\,000\ L_\odot$, the photospheric radius at maximum is estimated to be $570\ R_\odot$.

With this radius and the spectroscopically determined velocity of V = 1800 km/s at maximum, the time of outburst can be estimated to t_0 = Aug. 28.3 UT 1975 (i.e. about 2.6 days before maximum). The time of the onset of the explosion was also determined from infrared data by Ennis et al. (1977). Assuming that the emission is coming from an optically thick gas of constant temperature ($T \approx 10\,000$ K) and constant expansion velocity they get an outburst time of t_0 = Aug. 28.5 UT, 1975. Nova Cyg 1975 is also remarkable because of available pre-eruption observations between Aug. 6 and Aug. 25, 1975 (Alksne et al. 1975, Samus 1975), and of observations during the steep rise to the maximum carried out by Garnavich and Mayer (Liller et al., 1975) (Fig. 11).

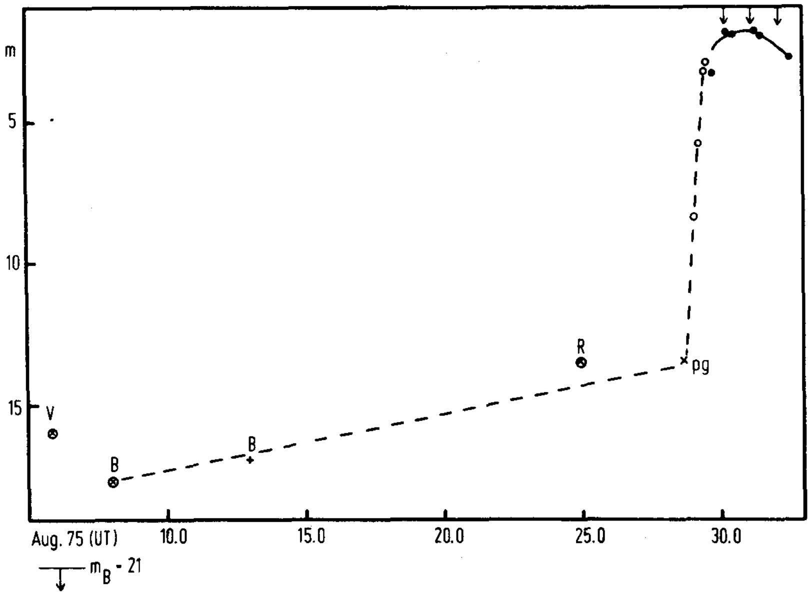

Fig. 11: The premaximum of Nova Cyg 1975. Note that the final steep rise occurred from an "excited stage" lying more than 5 magnitudes above the prenova luminosity. The symbols denote the observations from:

⊗ Aksnese, Platais (Riga)   X Suyarkova (Dushanbe)
\+ Samus (Sternberg Obs.)   O Garnavich (Maryland)
Mayer (Los Angeles)

From this diagram the most probable date of the onset of the explosion is determined to t_o = Aug. 28.7 UT, 1975, which agrees surprisingly well with the other two values. From this good agreement one may conclude that the velocity of the expelled principal shells has remained more or less constant from the onset of the explosion until the maximum light. From infrared observations around maximum a maximal temperature of T = 10 000 K of the expanding gas during the early phases is indicated (Gallagher and Ney 1976, Ennis et al. 1977). Assuming that during the steep rise of the light curve after the onset of the explosion

a) the temperature has been constant (T = 10 000 K),
b) the expanding plasma has always been optically thick in the continuum,
c) and the velocity of expansion has been constant (v = 1800 km s^{-1})

photo visual magnitudes m_{pv} have been calculated.

A comparison with the observed m_{pv} values of Garnavich and Mayer (Fig. 12) shows that the calculated curve lies always higher, but almost agreement is reached at date Aug. 29.5 UT (1.4 days before maximum).

A possible explanation for this could be that the temperature has not been constant during the early rising branch. An admittedly rather uncertain indication for a rather low temperature of the prenova can be derived from the prediscovery observations of Alksne (1975) and Samus (1975), yielding B-V = $1\overset{m}{.}3$, V-R = $2\overset{m}{.}5$, if the prenova did not vary irregularly during early August 1975. Thus, the early evolutionary phases of V 1500 Cyg up to about maximum light can be tentatively summarized as follows:
The outburst started from a presumably rather cool (T $\approx$ 4000 K) "excited object" (more than 5 magnitudes above the prenova luminosity) on Aug. 28.5 UT, 1975. [Studies of preeruption lightcurves of novae by Robinson (1975) have shown, that a small increase in luminosity ($\lesssim$ 1.5 mag) prior to eruption is not unusual; however the preeruption "excitation" of more than 5 mag above the prenova of V 1500 Cyg seems again unique] .

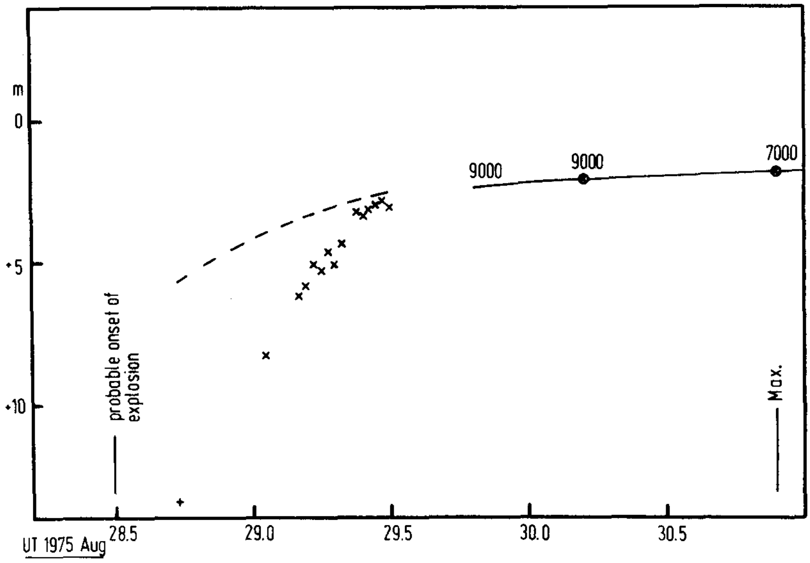

Fig. 12: Comparison of calculated magnitudes during the rising branch with observations (X Garnavich, Mayer; + Suyarkova; x photoelectric V measurements). Full line represent calculation with T = 9000 K rsp. 7000 K corresponding to the temperatures of Table 5. The dashed line represents calculations with T = 10 000 K. All calculations were carried out for constant velocity of the expanding shell (v = 1800 km s^{-1}).

The ejected gas expanded with a nearly constant velocity of about 1600 to 1800 km s^{-1}. From the existence of several components in the emission lines which are discernible practically from the beginning one has to conclude that different clouds have been expelled either within a short time interval or simultaneously (Fehrenbach and Andrillat [1976] suggest a model with two polar caps and two equatorial rings, Boyarchuk and Gershberg [1977] suggest two polar caps and an equatorial ring, whose plane forms an angle of about 60° with the line of sight). The temperature has presumably increased during expansion due to dissipated shock energy from about 4000 K to about 10 000 K. One day later (about Aug. 29.5 UT, 1975) another shell with a velocity of about 4000 km s^{-1}, corresponding to the diffuse enhanced spectrum, was ejected and penetrated the main shell(s) without noticeable interaction. As the diffuse enhanced spectrum was very faint one has to conclude, that the great majority of the material has been expelled in one explosive event at the primary outburst.

7. The Binary Nature and the Short Term Variability Period of Three Hours

During the past twenty years evidence has been accumulated that all novae occur in close binary systems (c.f.e.g. Kraft, 1963) where mass is transfered from a late type star, filling its critical Roche volume, to the white dwarf component of the system. The matter forms an accretion disk around the white dwarf. After a sufficient amount of hydrogen rich material is accreted by the white dwarf, in the case of classical novae a thermonuclear reaction is ignited, which gives rise to a thermonuclear runaway. Thermonuclear runaway models of nova outbursts have been worked out for spherical symmetric accretion (Starrfield et al., 1976a). Although the problem is certainly not spherical symmetric (Kippenhahn and Thomas, 1977) the outlined general picture of a nova outburst has been widely accepted. Therefore it was rather surprising when Starrfield et al.(1976b) came out with a single-star interpretation of Nova Cyg 1975. As main reasons for justifying their hypothesis they quoted

a) the rounded lightcurve of Nova Cyg which fits very nicely the lightcurves of the single star thermonuclear runaway models,

b) the low luminosity of the prenova [in fact the prenova had to be fainter than +9, as can be estimated from the absolute magnitude of ~ -10 at maximum and from the brightening of at least 19 magnitudes. This implies that in case of a binary interpretation the late type companion had to be later than M0 and very little tolerance remains for a bright disk] ,

c) and the absence of high velocity absorption lines, specifically of the diffuse enhanced absorption lines [about the origin of the high velocity systems the authors speculate that they "might arise in interaction between the expanded envelope of the white dwarf and the companion"].

As there is no mass transfer from a binary companion in the case of an isolated white dwarf, accretion from interstellar material is offered as an alternative. This "isolated white dwarf" interpretation has been opposed by various authors: First, it should be mentioned that the diffuse enhanced system was found (Duerbeck and Wolf, 1977). The strongest argument against the single star interpretation is the short period variability which has been detected by Tempesti (1975 a, b, c) and Koch and Ambruster (1975 a, b) with a period of 3.4 hours with changing amplitude ($0^m.15$ in Sept. 9/10 and $0^m.12$ in Sept. 14/15) (Fig. 13). Semeniuk et al. (1976) found that the period was gradually changing from $0^d.1415$ to $0^d.1382$ between Sept. 12, 1975 and June 1976.

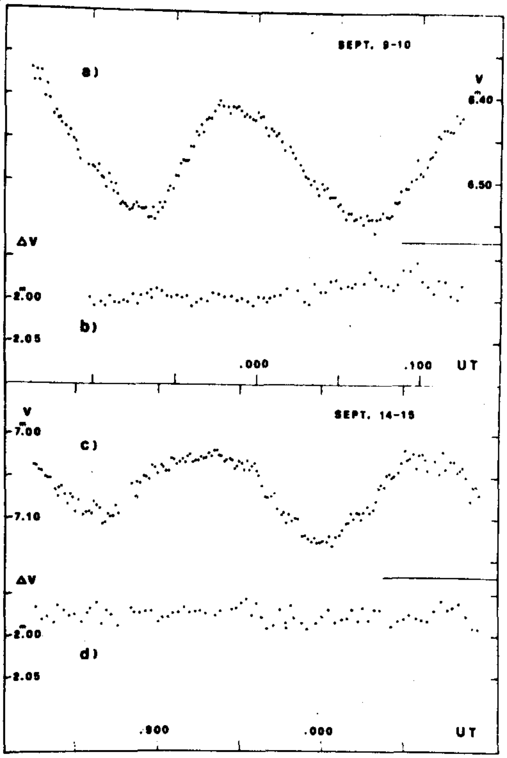

Fig. 13: Light curves (a and c) of Nova Cyg 1975 showing the 3.4 hours period (Tempesti 1975 c)

The satellite UV observations of Wu and Kester (1977), one hundred days after visual maximum confirm a period of $0^{d}.140$ of the central remnant.

The variations are most naturally explained as geometric in origin due to a close binary system. Possible mechanisms to explain the observed period changes have been suggested as well. Wu and Kester (1977) ascribed it to changing location and size of the hot spot and the variable rate of mass transfer. Fabian and Pringle (1977) explain the period changes by a model in which the binary system creates a spiral density variation in the outflowing wind, that has its origin from the degenerate dwarf.

The radius of the remnant was 100 days after the visual maximum according to Wu and Kester (1977) about 10^{11}cm and its temperature was about 65 000 K.

8. Ejected Mass and Energy Output

A presumably lower limit of the mass of the ejected main shell(s) can be calculated from the absorption components of the Balmer lines at maximum. At maximum the continuum is about getting sufficiently transparent and therefore it can be assumed that at least the higher Balmer lines are absorbed in optical thin layers and the simple formula can be applied

$$W_{\lambda} = \frac{\lambda \pi e^2}{mc^2} f n_{o,2} \Delta R$$

(f = oszillator strength, $n_{o,2} \Delta R$ = column density, W_{λ} = equivalent width)

Table 6: The equivalent widths of the Balmer absorption lines and the calculated column densities

Line	W_{λ} [m Å]	$n_{o,2}$ ΔR
H_{α}	8600	7.0×10^{13}
H_{β}	8100	6.6×10^{14}
H_{γ}	5900	1.6×10^{15}
H_{δ}	6450	2.6×10^{15}

The extrapolation to higher quantum numbers ("reduction to the optical thin case") yields the value

$$n_{o,2}\Delta R \approx 3 \times 10^{15}.$$

With the temperature T = 7000 K at maximum and the electron density $N_e \sim 10^{10}$ cm^{-3} (this is a plausible value for the plasma of the expanding shell at maximum (Ennis et al., 1976), one gets with the Boltzmann and Saha formulas the column density of protons (which is practically the total amount of hydrogen under these conditions)

$$n_1 \Delta R = 4.2 \times 10^{23}.$$

With the estimated radius at maximum ($R \approx 570 R_\odot$) we get the mass of the ejected shell from the relation

$$M = 4\pi R^2 \Delta R\, n_1 m_H \mu_0 \approx 2.1 \times 10^{28}\ [g] \sim 10^{-5}\ M_\odot$$

(m_H is the mass of the hydrogen atom; μ_0 effective molecular weight; $R_\odot$ and $M_\odot$ denote solar radius and solar mass respectively).

The mass of the ejected material in the primary outburst has been estimated from infrared observations to $10^{-5} < M < 10^{-3} M_\odot$ (Gallagher and Ney, 1976) and to $\sim 10^{-4}\ M_\odot$ by Ennis et al. (1977). As the high velocity system (diffuse enhanced spectrum) was faint one may conclude, that the great majority of the material has been ejected at the initial outburst.

With $M_{\text{Shell}} \sim 10^{-5}\ M_\odot$ and the velocity of expansion V = 1800 km s^{-1} the kinetic energy of expansion is calculated to

$$E_{kin} \sim 3 \times 10^{44}\ [\text{erg}]$$

It is instructive to compare this with the radiated energy, which has been approximately determined from the measured optical and infrared luminosity during the first 11 days by Gallagher and Ney (1976) to

$$E\ (V + IR) \sim 5 \times 10^{44}\ [\text{erg}]\ .$$

The authors extrapolate that the expected total radiated energy would be E (rad) $\geq 10^{45}$ [erg] .

From theoretical studies of shocks moving through stellar envelopes (Hazelhurst 1962, Sparks 1969, Gallagher and Starrfield 1976) one expects that 10% of the initial energy appears as kinetic energy of expansion and that the rest goes into internal energy and gets radiated. This seems to be in reasonable agreement with the observations in Nova Cyg 1975.

In connection with the estimated ejected mass of Nova Cyg 1975 (also motivated by the subject of this Colloquium) one may ask about the efficiency of classical novae in recirculating of interstellar matter.

The frequency of classical novae events in the galaxy is not well known. The value usually quoted in the literature (e.g. Payne-Gaposchkin 1957) is ~ 50 per year. If one assumes a total ejected mass of 10^{-5} to 10^{-4} $M_\odot$ per outburst, then approximately 10^{-3} to 10^{-2} solar masses are shed by novae per year into the interstellar medium. This can be compared with the mass shed by supernovae explosions. The frequency of supernovae in Our Galaxy has been investigated by Tammann (1970, 1977). According to his statistics one galctic type II supernova explosion occurs about every 22 years. The progenitors of type II supernovae are supposed to be massive stars expelling $\sim 5\ M_\odot$ into the interstellar medium. Hence a rate of 0.2 $M_\odot$ shed material per year is expected. Therefore it is very likely that classical novae do not play an important role in the chemical evolution of the Galaxy, although it cannot be completely ruled out that novae are producing some rare isotopes (such as ^{15}N) on a galactic scale (Audouze and Lazareff, 1977).

II. Nova Vul 1976 (NQ Vul)

1. Introduction

Nova Vul 1976 was discovered on Oct. 21.764, 1976 by Alcock (IAU Circ. 2997). The visual magnitude at discovery was about $6^m.5$. Nova Vul 1976 is especially remarkable for its lightcurve which exhibits strong variability from the beginning. The lightcurve is perhaps comparable to the one of DN Gem which has two seperate maxima (Payne-Gaposchkin, 1957). In the case of Nova Vul 1976, the second maximum is very likely even brighter than the first one, which is exceptional and certainly difficult to understand on the basis of current theories of nova explosions.

2. Spectral Evolution and Radial Velocities

The spectral evolution of Nova Vul 1976 has been described by Rafanelli (1977) and Wolf and Klare (1977). Nova Vul 1976 developped very strong high velocity absorption systems. On a spectrogram taken on Oct. 26, 1976 (5 days after discovery) the typical principal spectrum is discernible with strong P-Cygni characteristics of the Balmer lines. The velocity of expansion is V = -952 km s^{-1} (Klare and Wolf, 1976 a). The Balmer line emission is structured with four components ranging from -80 to -600 km s^{-1} (see the tracing of Hβ of Fig. 14). In addition to the Balmer lines, Fe II- and Ti II- emission lines were identified.

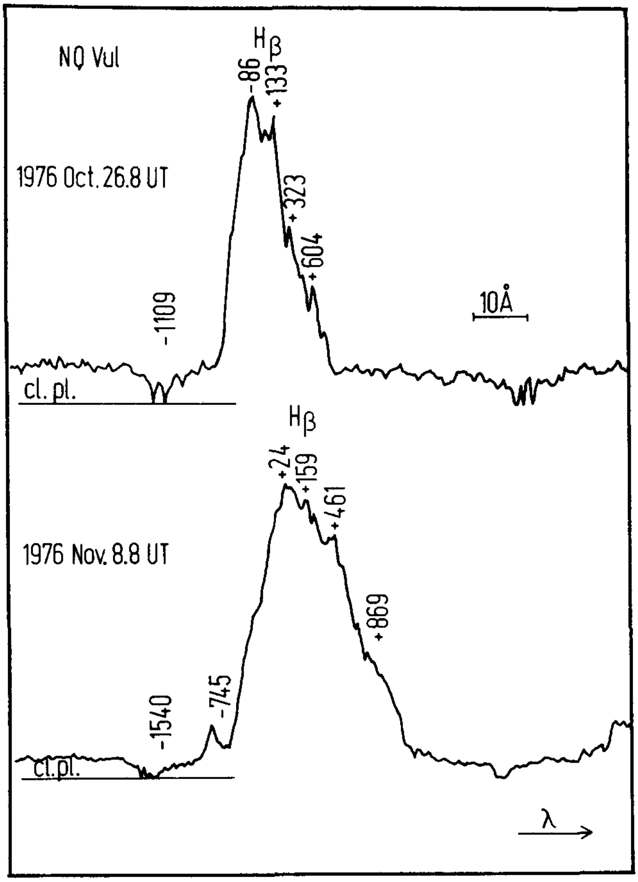

Fig. 14: Intensity tracings of Hβ of Nova Vul 1976. The spectrograms (dispersion 55 Å/mm) were taken with the Boller and Chivens spectrograph of the Landessternwarte, Heidelberg Königstuhl (Klare and Wolf, 1975a, b).

The spectrogram taken at Nov. 8.77, 1976 (Klare and Wolf,1976b) is characterized by broad and intense Balmer- and metallic (FeII, TiII) emission lines. In addition to the principal absorption spectrum very strong diffuse enhanced absorption components of the Balmer lines were found with a velocity of V = -1490 km s^{-1}. A several component substructure of the Balmer lines is again illustrated by the tracing of the H_β line (Fig. 14). In Fig. 15 intensity tracings of two spectrograms (dispersion 60 and 40 Å/mm) are shown, which were taken in Nov. 29.76 UT and Dec. 11.78 UT, 1976 at the Calar Alto Observatory, Spain.

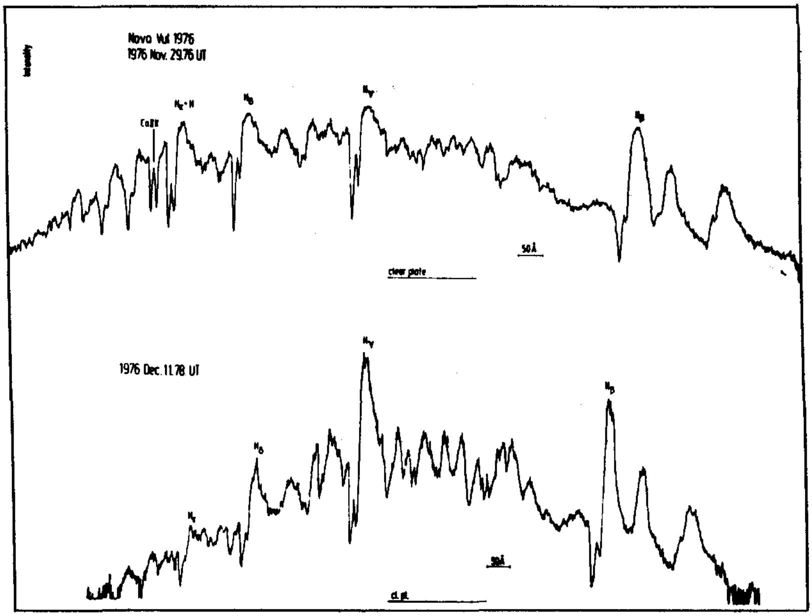

Fig. 15: Intensity tracings of Nova Vul 1976.

The spectrogram of Nov. 29.76 UT exhibits the strong Orion absorption system (in addition to the principal system) at a velocity of about -1700 km s^{-1}. On Dec. 11.78 UT the velocity of the Orion system has increased to about -1900 km s^{-1}. Variations of this order are not unusual; it is well known that the Orion absorption spectrum shows the largest radial velocity variations (Payne-Gaposchkin,1957). The radial velocities of the absorption systems as determined from the Balmer lines on spectrograms which were taken between Oct. 26 and Dec. 11, 1976 are listed in Table 7.

Table 7: Radial velocities of the absorption systems of the Balmer lines of Nova Vul 1976.

Date	V_p	$V_{d.e.}$	V_{orion}
1976, Oct. 26	- 952:		
Nov. 8	- 716:	-1489	
Nov. 25	- 903		-1723
Nov. 29	- 874		-1678
Dec. 8	-1046		-1949
Dec. 11	-1110		-1914

The width of the Balmer lines (emission + absorption) has increased from 2330 km s^{-1} on Oct. 26 to 3660 km s^{-1} on Nov. 8, and around Dec. 11, when the Orion system was present, to the high value of 4685 km s^{-1}. The strong increase of the line widths of the Balmer lines shows that necessarily faster particles do considerably contribute to the formation of the expanding envelope. Contrary to this, the total line width of the Balmer lines has varied only very little in the case of Nova Cyg 1975 (c.f. H_α scans of Fig. 4).

3. The Lightcurve and some Characteristic Data of Nova Vul 1976

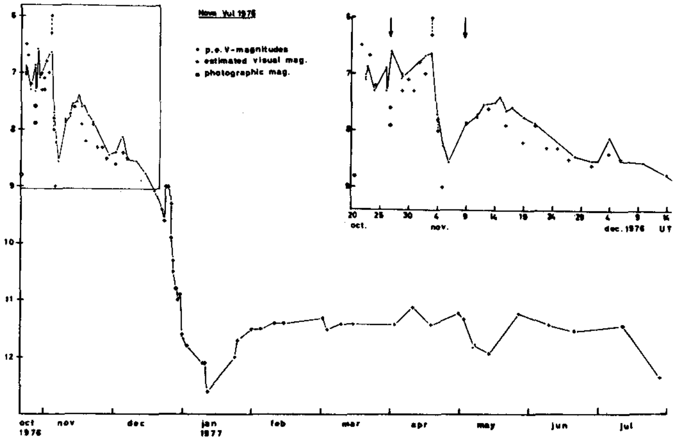

Fig. 16: The lightcurve of Nova Vul 1976. The data have been taken from various IAU Circulars.

The lightcurve of Nova Vul 1976 (see Fig. 16) exhibits strong variations. Note, that strong variations have been present from the beginning, immediately after discovery. The discovery occurred presumably near maximum as was concluded from a spectrogram taken at Lick Observatory (10.5 hours after discovery) by Harlan and Phillips (1976). It is also indicated by the photographic prediscovery observation (only one day before discovery) of Alksenov (1976) which yielded a considerably lower magnitude (see Fig. 16). It is especially noteworthy that there is a second increase in brightening on Nov. 3 which very likely reached even beyond the first maximum if one takes the magnitude estimates by several members of the American Association of Variable Star Observers (IAU Circ. No. 3003). This increase in brightening was followed by a dramatic decline of about 2 magnitudes within two days. The increase between Nov. 1 and Nov. 3 in brightness was also observed in monochromatic bandpasses. By comparison with the measured $H\beta$ intensity it was found that the increase in brightness was mainly due to a significant increase in the intensity of the continuum (Neff, 1976 a, 1976 b).

The main difference of our spectrograms from Oct. 26 and Nov. 8, 1976 is the diffuse enhanced absorption system, present on the second one. It is tempting to correlate the appearance of the diffuse enhanced spectrum with the second maximum which apparently was a second explosive event.

The second dramatic decline by about 3 magnitudes at two months after discovery was associated by dust condensation which occurred 65 days after discovery and produced a 1000 K black body infrared emission spectrum (Ney 1977). Some characteristic data of Nova Vul 1976 (which still have to be regarded as rather preliminary) are summarized in Table 8. From these data it is evident, that Nova Vul 1976 behaved quite normal concerning absolute magnitude at maximum, range of brightening, and the absolute magnitude of the prenova. It is a medium fast nova with a time of decline by three magnitudes of t_3 = 42 d.

Table 8: Some characteristic data of Nova Vul 1976

Prenova:	$m_{pg} \approx 18.3$
Apparent mag. at maximum:	$m_v \approx 6.5$
Range of brightening:	$\Delta m \approx 11.8$
Absolute mag. at maximum:	
a) from polarization measurements:	$M_v = -7.5 \pm 1.5$
b) from the lightcurve ($t_3 = 42$ d):	$M_v = -7.4$
Abs. mag. of the prenova:	$M_v \approx +4.4$

Concluding Remark

I tried to describe the observations of two rather different classical novae. Nova Cyg 1975 is outstanding and unparalleled by other known galactic novae. The characteristic data of Nova Vul 1976 (Table 8) on the other hand are normal. Apart from the numerical differences in absolute magnitude at maximum, range of brightening and so on, there is a remarkable difference concerning the light curves of both novae. Nova Cyg 1975 has a lightcurve with a rounded maximum and a very rapid decline. It is suggestive that the outburst was essentially one explosive event (compare also the weakness of the high velocity absorption systems in this nova). Lightcurves of the type of Nova Cyg 1975 compare reasonably well with those expected from theoretical models (Starrfield et al., 1975).

Nova Vul 1976 has a complicated lightcurve. The occurrence of a second explosion is indicated several days after the primary outburst. The second maximum surpasses even the first one in intensity.

It is certainly difficult to explain this kind of lightcurves on the basis of current theoretical models of a nova explosion. One is left with the strange situation that the nova with the conservative normal characteristic data (Nova Vul 1976) encounters more theoretical difficultis than the rather exceptional Nova Cyg 1975.

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DISCUSSION of paper by WOLF:

FRIEDJUNG: Most novae are like Nova Vulpeculae and difficult to explain. Is the second shell of Nova Cygni you assume, responsible for the diffuse enhanced system? How do you get it to penetrate the first shell? Would it not be better to assume continued ejection for the diffuse enhanced system?

WOLF: The second shell is responsible for the diffuse enhanced system. As noted in my talk, the shells apparently penetrate without noticeable interaction; at least the visual light curve remained very smooth.

In reply to Appenzeller, I said that absorption lines would have to be formed on the same line of sight, and that the problem of one shell stopping another could not be solved with such a hypothesis, unless there was some very small scale structure in the deviations from spherical symmetry.

APPENZELLER: One way out of the problem of one shell apparently penetrating the other could perhaps be a strongly non-spherical ejection. Don't we have evidence for such non-spherical ejection from older novae where we can observe the post-nova nebulae?

WOLF: Yes, we do have this evidence.

JOSHI: 1. How does one determine the absolute magnitudes of novae?

2. What are the reasons for the fluctuations in the declining branch of novae light curves? We have observed Nova Saggittarii 77 and find indications of fluctuations in the light and color curves in the declining branch.

WOLF: 1. In the case of Nova Cyg 1975, we determined the distance from the interstellar lines.

2. I am not aware of a generally accepted explanation of variations such as observed in the case of Nova Vul 1976.

KRAFT: Do the absolute magnitudes you derive from the strengths of interstellar features agree with those expected from the life-luminosity relation?

WOLF: Yes, very well. From the decline of 3 magnitudes, which occurred within 3-6 days, one gets $M_v = -10.1$, which agrees well with our direct determination of $M_v = -9.8$.

MATTEI: I would like to report that AAVSO visual and photoelectric observations do indicate that the nova brightened from $7^{m}_{\cdot}5$ to $6^{m}_{\cdot}0$ between Oct. 30 and Nov. 2. During the evening of Nov. 2-3, it dropped significantly, reaching $8^{m}_{\cdot}0$ in 24 hours.

SHAVIV: Do you have an estimate for the mass ejected in Nova Vulpeculae?

WOLF: No, I do not.

MERRILL: Based on infrared observations of Nova Vul 1976 E.P. Ney estimates M_{shell} about $10^{-5} M_{\odot}$; as an aid to understanding Nova Vul light curve, it should be noted that the sharp decline in visual flux near day 65, is matched by a corresponding rapid rise in infrared (2-20μ) flux, implying rapid dust formations approximate energy conservation is indicated.