PART 6

NOVAE

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NOVAE

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Abstract. This paper is a review of some of the most important problems on novae. Special attention is paid to the interpretation of recent observational data on novae, structure of the principal envelopes, infrared emission from novae and especially to the problems of magnetic fields in novae.

The novae belong to the classical type of variable stars. The nova outbursts attracted attention of people from ancient times. In historical chronicles more than 60 possible appearances of novae were described.

In our Galaxy more than 180 novae were observed up to 1974. The list of all galactic novae is quoted in the third volume of *GCVS* and in its Supplements.

1. The Photometric Observations of Novae

The general photometric behaviour of novae is well known. In 1939 McLaughlin (1939) described the main stages of the light curves common to each nova in spite of the great variety of nova curves.

There exist classifications of novae based on the rate of nova development (5 speed classes according to Payne-Gaposchkin) and on the forms of the light curve at early decline and transition (smooth, oscillations, dip).

The most complete information about all galactic novae observed up to 1956 as well as the data on the distribution of novae among speed classes were summarized in the book *The Galactic Novae* by Payne-Gaposchkin (1957).

After that about 30 novae were observed. Among them V 446 Her 1960 was extremely fast ($t_3 = 12^d$), FH Ser 1970 had a pronounced light curve of DQ Her type, and HR Del 1967 was characterized by very slow development. The light curves of several recent novae in V system are shown in Figure 1.

It has already been emphasized many times that the brightness of novae in a wide-band photometric system is to a considerable degree due to the emission lines which strengthen as the brightness declines (Vorontsov-Velyaminov 1934; Bronkalla and Notni, 1962; Fernie 1969; and others). For the observations of novae, the UBV system is now widely used. The most intense emission lines of novae spectra fall on the edges of the *B* and *V* spectral bands: λ 4861 Hβ, 5007 N_1, 4959 N_2. Therefore the slight variations of individual response curves from the 'standard' UBV system result in significant systematic discrepancies in simultaneous brightness estimates obtained with different *UBV*-photometers. This is illustrated in Figure 2 where the light curves of

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V 533 Her 1963 obtained by Chincarini (1964) and by van Genderen (1964) are compared.

The reductions of such observations to the single system are very difficult and usually not possible at all, especially at the nebular stage, owing to the continuous change of the nova spectrum.

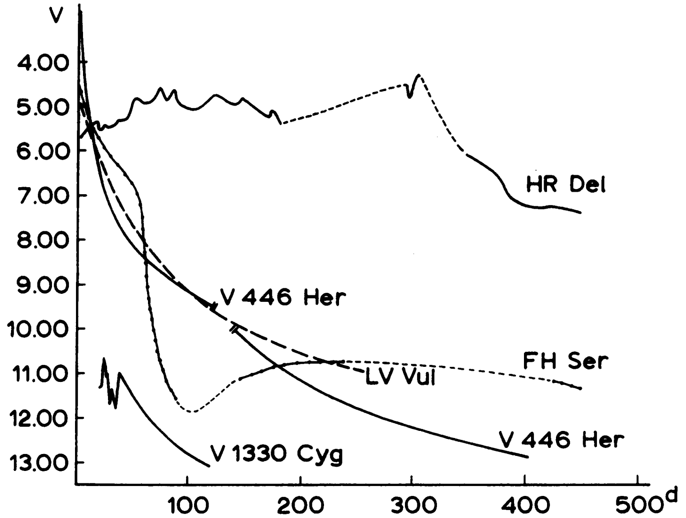

Fig. 1. The light curves of several recent novae: HR Del (Barnes and Evans, 1970) – FH Ser (Borra and Andersen, 1970) – V446 Her (Bronkalla and Notni, 1962) – V1330 Cyg (Zaitseva and Lyuty, 1970).

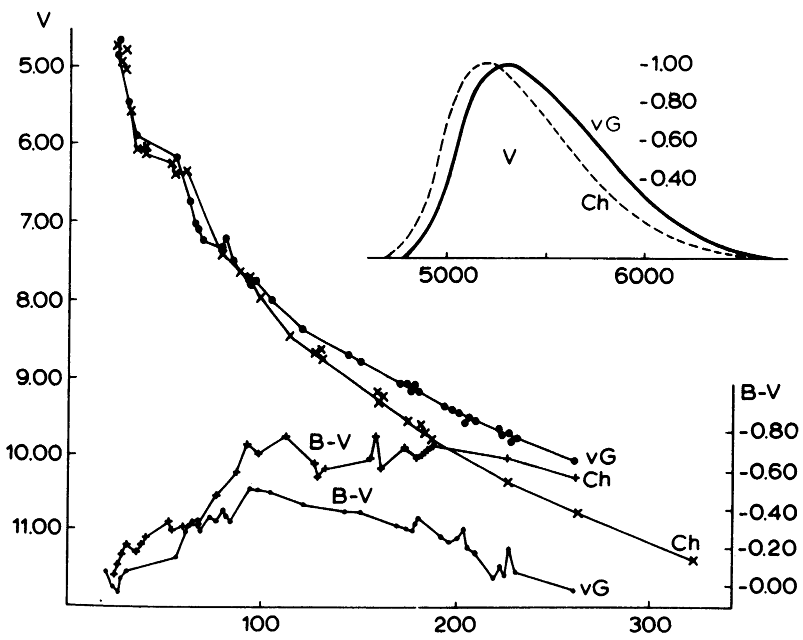

Fig. 2. The light curves of V 533 Her in V and $(B-V)$ systems according to Chincarini (1964) and van Genderen (1964). The response curves of the systems are shown.

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The high precision of the photoelectric photometry turns out to be unrealized when constructing the mean light curves of novae. The mean light curves derived from the data by different observers therefore can be affected by various errors which may even lead to the appearance of fictitious features.

Owing to the enormous influence of emission lines the behaviour of novae in the two-colour diagram is very erratic (Figure 3).

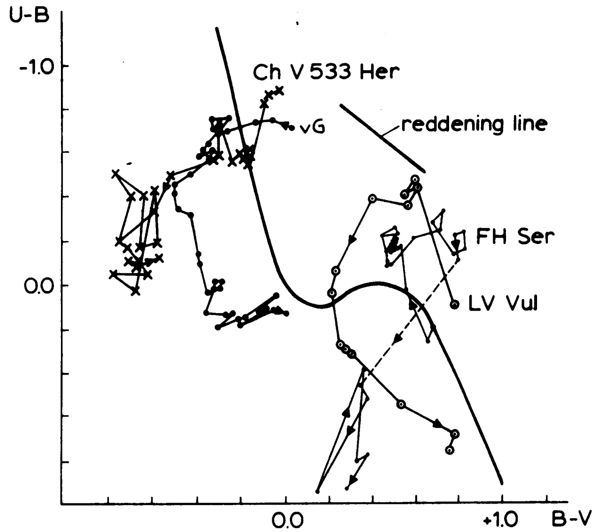

Fig. 3. The tracks of novae in the two-colour diagram.

The problem of a suitable photometric system for novae has been discussed for a long time. In such a system the star brightness variations should represent true continuum brightness variations.

As the investigations by Tremko (1973) show, there is no sufficiently wide region with pure continuum in the nova spectrum in interval 3000–6500 Å. But in the near infrared there are several regions without emission lines. One such band with the width of 400 Å is located between the emission lines λ 6678 Å He I and λ 7065 Å He I (if we neglect the line λ 6919 Å A I in the later stages). The widest band is bordered by the spectral lines O I 7772 Å and 8216 Å but it contains several faint emission lines. The continuum regions of about 200 Å wide are also located at 7460 Å and 8340 Å.

Observations of novae with narrow and intermediate band filters were performed by Prokof'eva and Belyakina (1961) (V 446 Her 1960 in red and infrared), by Gyldenkerne *et al.*, (1969) (V 446 Her in λ 4033, and λ 3975 Å), by Catalano *et al.*, (1968) (HR Del 1967 at λ 4954 and λ 3975 Å) and by others.

At Vilnjus observatory the seven-colour intermediate band system *UPXYZVS* was used for the observations of HR Del (Žitkevičius and Sudžius, 1969).

However as a whole the question of the optimal photometric system for the observations of novae is still open. The practical results in this direction are also rather poor.

But the UBV system is still suitable for the observation of novae at minimum brightness.

It is known that novae at minimum brightness show, as a rule, irregular variations with rather small amplitudes. This variability seems to be unrelated to the recency of outburst or to the characteristics of the nova. Thus, GK Per 1901 has continuous variations with $A_V \simeq 0^m.5$ (Mumford, 1966) and V 533 Her 1963 shows irregular fluctuations with a range $0^m.1$–$0^m.2$ and duration of 5–50 min (Chincarini and Howard, 1966). The observations of WY Sge 1783 carried out by Brian (1971) at McDonald observatory yield an amplitude $0^m.1$–$0^m.2$ with a duration of 5–15 min. Stienon (1971) has found a different photometric behaviour of V 446 Her 1960 before outburst and after it: the star which was variable with a range up to 2^m and characteristic time of 20–30 days became, after outburst, only a slight variable with amplitude of $0^m.1$.

Besides the irregular brightness variations, novae display also periodic light variations of pulsation type. Thus, DQ Her has strictly sinusoidal oscillations with a period of 71 s and amplitude of $0^m.02$.

The observations of novae at minimum brightness led to the discovery of their duplicity. In 1954 Walker (1956) found the eclipses of DQ Her recurring with a period of 4^h, in 1963 he (Walker, 1963) found T Aur to be an eclipsing variable with $P = 4^h54^m$. The duplicity of other novae – GK Per, V 603 Aql, recurrent nova V 1017 Sgr – was discovered spectroscopically. The short periods of eclipsing novae suggest a close pair consisting of a hot component - subdwarf and a star of later spectral class. The luminosity of the blue component is usually higher than that of the red. The observations of eclipsing novae allowed for the first time trustworthy estimates of nova masses. The summary of the masses and luminosities of components for all investigated binary novae is given in Table I (Mumford, 1967).

TABLE I

The periods, masses and luminosities of binary novae

Star	P	Eclipse	M_V(red)	M(blue)	Masses		Note
					red	blue	
Typical novae							
GK Per	$1^d.904$	no?	+4.5	–	>1.29	⩾0.56	Kraft (1964)
	0.685		–	+5	0.3	0.06	Paczyński (1965)
T Aur	0.2042	yes	⩾+5.0				Walker (1963)
DQ Her	0.1938	yes	⩾+9	<+7	0.12	0.20	Kraft (1964)
V603 Aql	0.1385	no	⩾+5				Kraft (1964)
Recurrent novae							
T CrB	227.6	no	+0.2	–	2.6	3.7	Kraft (1964)
	227.5			+1.7	1.9	2.6	Paczyński (1965)
WZ Sge	0.0569	yes	⩾+11	>+7	0.6	0.03	Krzemiński and Kraft (1964)
						>1	Krzemiński and Smak (1969)

2. Observations of Novae in Other Spectral Regions

In recent years one of the most remarkable discoveries in the history of novae investigation was made – their strong infrared emission was found (Hyland and Neugebauer, 1970; Geisel *et al.*, 1970). Geisel *et al.*, (1970) have made observations of FH Ser, HR Del, V 1229 Aql, recurrent novae RS Oph and T CrB in the *VKLMNQ* system from 0.5 to 22 μ. They found that FH Ser was one of the brightest infrared stars in the sky, being $N = -4\overset{m}{.}0$ after 101 days from the outburst. The light curves of FH Ser in the infrared taken from the paper by Geisel *et al.* are given in Figure 4.

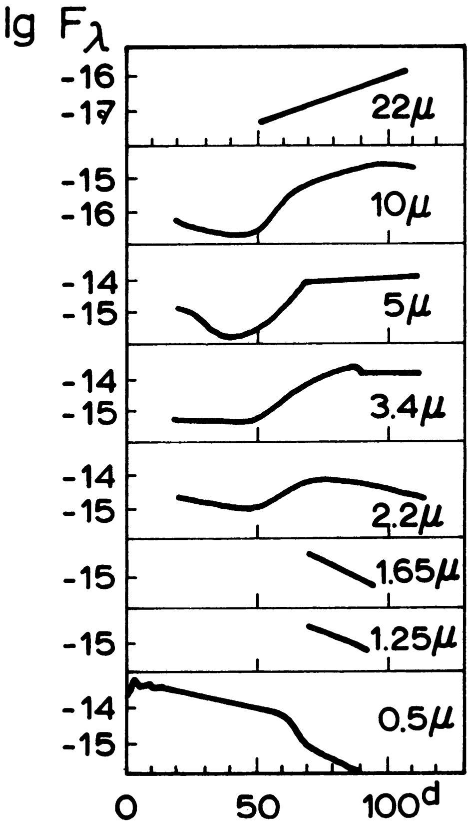

Fig. 4. Infrared light curves of FH Ser.

The observations show clearly that the infrared emission appears after the maximum brightness and increases with the brightness decline. As the nova decreases the maximum of infrared emission shifts to the longer wavelengths. The IR source is comparable in output with the optical energy of the nova. At the minimum brightness there are no large infrared excesses as the observations by Feast and Glass (1974) show.

At present it is generally accepted that the IR emission of novae is due to thermal radiation from the dust particles in an expanding shell ejected or formed during the outburst. The temperature of the shell dust at IR maximum is estimated to be 900°. For FH Ser it decreased from 2000° to 600° during the observational period. The dust formation is a general property of large-scale mass loss, as the observations of novae, P Cyg stars, Be stars and other objects show.

Are there any traces of dust in the optical region of novae spectra?

The observations by Hutchings and Fisher (1973) of profiles of emission lines in the FH Ser spectrum imply that the reddening of the approaching part of the nova shell is less than that of the receding part. Malakpur (1973a) has found variable extinction from the Balmer decrement of HR Del. It is caused, in his opinion, by the altering of the size of absorbing particles in the dust shell of the star.

The polarimetric observations are also evidence in favor of dust in the nova shell. Arsenijevic and Kubicelo (1970) found variable optical polarization of HR Del due to the circumstellar shell. Zellner and Morrison (1971) carried out polarimetric measurements of HR Del, LV Vul and FH Ser, and found in HR Del variations of 0.5 to 0.8% in the degree of polarization in the course of some months and smaller variations in the course of some days. They also found the variable polarization in FH Ser. The dependence of circumstellar polarization on wavelength is similar to the interstellar one (Zellner, 1969).

In recent years, radio observations of novae have been made. Wade and Hjellming (1971) detected radio emission from HR Del and FH Ser at 9.5 mm and from FH Ser at 3.5 mm. These novae were also detected at 11.1 and 3.7 cm. In the course of 4 months the flux-density of FH Ser increased by a factor of 3 at centimeter wavelenghts; the flux from HR Del showed no essential change. Novae have thermal radio spectra. The increase of radio flux is the result of the expansion of the nova shell, optically thick at centimeter wavelengths. The optically thick part of the radio spectrum of a nova does not have such a steep decrease as sources with constant emission measure do owing to the non-uniformity of the shells. Herrero *et al.* (1971) detected variable radio emission from V 368 Sct too.

The observable spectral region of novae was also extended to the shorter wavelengths. Gallaher and Code (1973) carried out observations of FH Ser in 7 filters from 1430 Å to 4250 Å with the satellite OAO-2 during 2 months from 1970, February 18 to April 13. At the beginning of observations, the radiation at $\lambda < 2000$ Å was absent and appeared only at the end of March. The wavelength of maximum continuum intensity shifted to shorter wavelengths.

3. Novae in Other Galaxies and the Luminosity of Novae

Many novae were detected in M 31 as a result of a systematic survey. The systematic searches for novae in M 31 were started in 1917 at Mount Wilson. Hubble (1929) gave a list of 84 novae discovered between 1909 and 1927. The extension of the systematic survey was carried on by Arp (1956) who found 30 novae in 1953–55. Arp established the significant relation between the maximum magnitude of a nova and the rate of its decline. The frequency of occurrence of novae in M 31 was found by Arp to equal 26 stars per year. In 1957 a systematic search for novae in M 31 was initiated at Asiago with the 122-cm telescope. As a result of this work, 90 novae were discovered (Rosino, 1964, 1972). Since 1960 the photographic observations of M 31 at Tautenburg added more than 30 novae (Börngen, 1968). Isolated novae in M 31 were also discovered by many other observers. At present more than 240 novae are known in M 31. The frequency of appearance according to Sharov is 29 ± 1 novae per year.

The total numbers of the known novae in other galaxies are as following:

M 31 (Sb) – > 240 novae	M 81 (Sb) – 25	NGC 147 (E) – 1
M 33 (Sc) – 12	NGC 205 (Ep) – 1	NGC 185 (E) – 1
NGC 2403 (Sc) – 1	LMC – 12	
IC 1613 (Irr) – 1	SMC – 4	

The frequency of novae in M 33 (Sc) is about 1 star per 2 yr from the systematic survey. The upper limit of the frequency of novae in galaxies of the Local Group – M 32, NGC 205, NGC 147, NGC 185 – was found by Arp (1956) to be equal $\frac{1}{2}$ star per year.

Sixteen novae are known in the Magellanic Clouds at present, 4 novae being in the SMC. The data from the systematic survey the LMC and SMC give the frequency of novae occurrence not higher than 1 nova per 2 yr (Henize *et al.*, 1954). The objective prism observations of Magellanic Clouds by Graham and Araya (1971) made in 1970–71 led to the discovery of 2 novae during one season. Perhaps the frequency of novae in Magellanic Clouds is higher than that shown by Henize *et al.*, but it is essentially lower than for M 31. Novae in the LMC and SMC reach at maximum 11–12 apparent magnitude. Two thirds of the novae are outside the densest part of the Magellanic Clouds and not one nova has been found near the well-known gaseous nebulae or supergiant clusters.

Three galactic novae are possibly connected with globular clusters: the very fast T Sco 1860 in M 80, V 1148 Sgr in NGC 6553 and one nova in M 14 (outburst in 1938).

The essentially different frequency of occurrence of novae in various stellar systems is an observational fact; it is the highest in Sb galaxies and very low in elliptical, irregular and Sc galaxies (Kopylov, 1955). Probably it is closely connected with the stellar population of the galaxy and is maximum in Sb galaxies which are very rich in intermediate subsystem objects: novae belong to that system, too. It is also not excluded that the percentage of double stars is higher in galaxies with extensive disc population.

In our Galaxy the frequency of occurrence of novae is very uncertain. Assuming that all novae brighter than 3^m are discovered and taking the mean absolute magnitude at maximum $M = -7\overset{m}{.}3$, the lower limit of frequency of galactic novae is 50 per year (assuming that the subsystem of the novae is a disc with $z = 1$ kps). A higher value is derived if we assume that the novae subsystem of our Galaxy is analogous to that of M 31.

The novae in other stellar systems are good indicators of distances and give valuable information about luminosities of novae. In our Galaxy the luminosities of novae are determined with great uncertainty. The survey of methods used for this purpose is contained in the book by Payne-Gaposchkin (1957), in the paper by McLaughlin (1960) and others. According to Payne-Gaposchkin the average visual absolute magnitude of a typical nova at maximum is $-7\overset{m}{.}3$. McLaughlin gives $M_{\max} = -8\overset{m}{.}3$ for the fast and $-6\overset{m}{.}2$ for the slow novae.

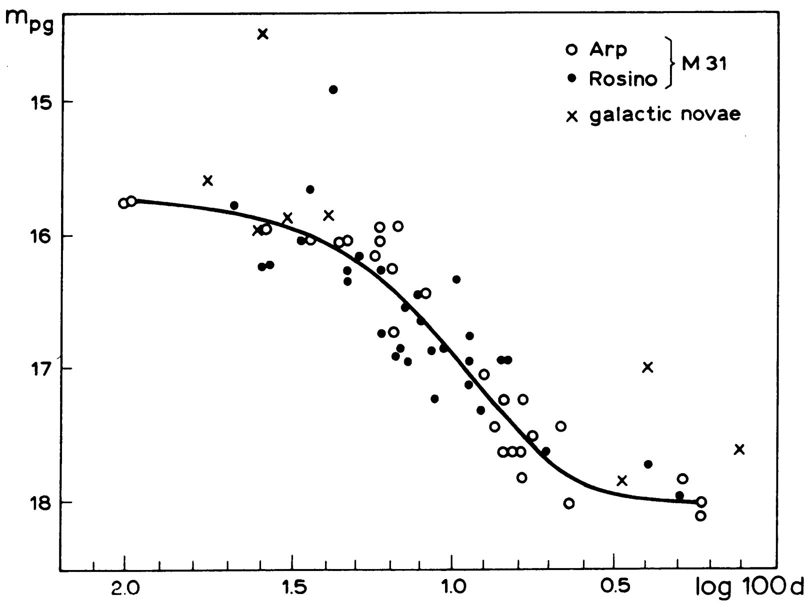

Fig. 5. The relation between $m_{\max}$ and the rate of the decline d (magnitudes per day) for M 31 novae according to Rosino (1964).

The relation between the absolute magnitude and the rate of decline t_3 for the galactic novae was derived by McLaughlin (1942), Kopylov (1955), Payne-Gaposchkin (1957). The latest determinations of distances and interstellar extinction give this dependence in the form $M_{0V} = -11.5 + 2.5 \lg t_3$, as deduced by Schmidt (1957) and revised by him in 1963 (Schmidt-Kaler, 1963).

The novae in the Magellanic Clouds were used by Buscombe and de Vaucouleurs (1955) for the investigation of the mentioned relation. If one accepts for the distance modulus of the Magellanic Clouds $m - M = 18\overset{m}{.}6$, the relation $M_{\max,\,\mathrm{pg}} = -10.9 +$ $+ 2.3 \lg t_{3_{\mathrm{pg}}}$ derived by them leads to identical absolute magnitudes of novae in the Magellanic Clouds and in our Galaxy.

Arp (1956) found that novae in M 31 closely fit the relation between luminosity and t_3 for the galactic novae. Rosino (1964) derived this relationship shown in Figure 5.

TABLE II

The distances and luminosities of several recent novae

Star	Type	t_3	M_B	M_V	r(pc)
V446 Her	vF	12 (B)	−8.7		900
V533 Her	F	38 (V)		−7.5	1300
HR Del	vS or RT Ser	:		−4.4	400
LV Vul	mF	46 (B)	−7.8		1300
FH Ser	mF	60 (V)		−7.4	730
IV Cep	F	38:(V)			3200

vF = very fast
F = fast
vS = very slow
mF = medium fast

The rate of decline d is a more convenient parameter than t_3 because it allows the use of fragmentary light curves of novae for the determination of absolute magnitudes.

The luminosities and distances of several recent novae are presented in Table II.

4. The Space Distribution of Novae

The structure of nova subsystem has been discussed by Bottlinger (1933), McLaughlin (1942), Kukarkin (1949), Kopylov (1955), and Payne-Gaposchkin (1957). Kukarkin drew attention to the unusual combination of strong concentration of novae in the galactic plane with equally strong concentration towards the galactic centre. Kopylov (1955) determined the parameters of the subsystem in the solar neighbourhood ($r<1500$ pc) and found that the gradients of space density of novae along r- and z-coordinates are typical for intermediate subsystems.

There are some indications that the slow novae do not have the same space distribution as the fast novae, the RT Ser-type novae (slow) seem to belong rather to the spherical component of the Galaxy (Głębocki, 1970).

There exist several novae at very great distances from the Sun placing them outside our Galaxy. These are GR Ori, V 522 Sgr, V 939 Sgr and some others. A unique nova was V 592 Her which has $r=63$ kpc and $z=42$ kpc (Richter, 1968). RW UMi also falls outside the Galaxy. But in some cases the adopted luminosity may be too high.

A favorable opportunity for the investigation of a nova subsystem is given by the novae in M 31. The distribution of novae in M 31 was discussed by Hubble (1929), Arp (1956), and Rosino (1964). They noted the appreciable sphericity of the subsystem. A very detailed study of the novae distribution in M 31 was made by Sharov (1971) who showed that the novae subsystem has composite structure. Near the nucleus of M 31, novae have a spherical distribution with a small axial ratio; at distances of 2–3 kpc from the nucleus, the structure changes abruptly and the subsystem turns into an intermediate one. The gradients of star density in the r and- z-directions are respectively:

$$\left.\begin{aligned} -\frac{\partial \lg D}{\partial r} &= 0.81 \\ -\frac{\partial \lg D}{\partial z} &= 1.30 \end{aligned}\right\} \begin{array}{l}\text{for the nucleus} \\ r \leqslant 2\text{–}3 \text{ kpc}\end{array} \qquad -\frac{\partial \lg D}{\partial r} = 0.16 \left.\right\} \begin{array}{l}\text{outer parts} \\ \text{up to } r = 17 \text{ kpc}\end{array}$$

It is possible that in the outermost of M 31 the novae subsystem is more flattened still.

The observations of novae in our Galaxy do not contradict this picture: the stars with the greatest z-coordinates are observed in the direction towards the galactic centre.

In M 31 as in the Galaxy, there exist several novae very far from the nucleus of the galaxy. Meinunger (1971) has found 4 novae outside the main body of M 31. They seem to be intergalactic novae.

5. On a Model of a Nova before Its Explosion and the Origin of the Explosion

There are many reasons for stating that all novae and recurrent novae are close binary systems with short periods of revolution, usually of a few hours. One star in the system is a small hot star; its companion is a relatively cool star of larger size.

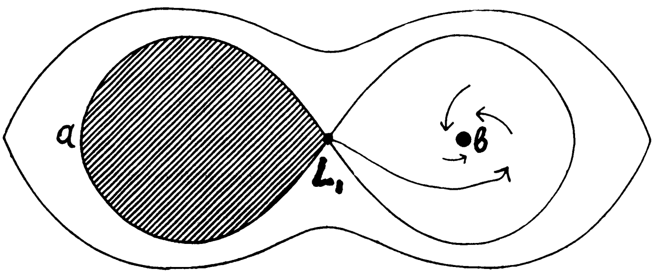

Fig. 6. Model of a nova binary system: a = the cool star, b = the hot star.

The most important property of the novae binary systems are the streams of gases from the cool star directed towards the surface of the hot star. It is accepted that this outflow of gas is in accordance with the model suggested by Crawford and Kraft (1956); see Figure 6. It is supposed that the cool star fills its Roche lobe and that the streams of gases from the cool star are directed mainly to the hot star through the inner Lagrangian point L_1. This leads to the formation of an emitting '*disk*' around the hot star. The conclusion that such disks (or some similar formations) do exist in novae was made by Kraft (1959) on the basis of spectroscopic and photometric data obtained for DQ Her after its explosion.

Now about the origin of explosion of novae. Here the starting point is the fact that, in certain cases, the small hot star in the novae systems has many properties inherent to the classical white dwarfs, see for example Table IV. Correspondingly many investigators (for example, Starrfield *et al.*, 1972) accept the idea of Kraft (1962)

> ... that the principal *exploding* star in all binary systems of novae is the hot star which is considered as a *white dwarf*. The larger, cooler star is losing hydrogen-rich material and a fraction of this material is being accreted by the white dwarf. As the accretion continues, a shell of hydrogen-rich material will be built up on the surface of the white dwarf and the *bottom* of this shell will be gradually compressed and heated until it reaches the ignition temperature for the hydrogen-burning reactions. It is expected that a thermonuclear runaway will occur in the hydrogen-rich envelope.

One of the recent investigations in this field is the just mentioned paper of Starrfield *et al.* (1972). The computations presented in this paper lead, in particular, to the conclusion that atoms of C, N, and O play a very important role in the nova explosion and that the abundance of these elements must be *enhanced* in the exploding (hydrogen-rich) shell of the nova as well as in the envelope ejected by the nova. This last prediction is completely confirmed by the chemical analysis of novae; see Section 7.

6. The Explosion of a Nova and the Ejection of the Principal Envelope

We have no observational information on the first stage in the explosion of a nova and only a very limited number of novae were 'discovered' before light maximum t_m when they were already in a state of rapid expansion. This process of expansion was studied in detail by Mustel (1945, 1948) and was summarized in subsequent review papers of Mustel (1957, 1970a). According to these studies the 'photosphere' of the nova stops expanding approximately at light maximum t_m, whereas the outer parts of a very extended 'reversing layer' of the star continue to expand. After the moment t_m these outer parts of the reversing layer are detached from the star and are transformed into the *principal envelope* of the nova, see further. Such a model of a nova is shown in Figure 7. The region S is the region of the 'detachment' of the envelope.

Several considerations show that the luminosity of the nova at light maximum is mostly due to the photosphere of the star. The contribution of the reversing layer to the luminosity is expected to be negligibly small (Mustel (1957) and Finzi (1973)).

Now let us consider the process of the formation of the principal envelope. Here the main sources of information are the spectra of the novae which were observed before and during light maximum. These novae are: GK Per (1901), DN Gem (1912), V 603 Aql (1918), V 476 Cyg (1920), RR Pic (1925), DQ Her (1934), and CP Lac (1936). The spectra of all these novae before t_m were characterized by a system of rather strong absorption lines (usually with weak emission components), displaced according to Doppler's law towards shorter wave lengths. This is usually called the *pre-maximum spectrum* (system α in Figure 8). McLaughlin (1960) found that almost immediately after light maximum the pre-maximum spectrum for all the enumerated novae was replaced by a new system (system β in Figure 8), the *principal spectrum**, with a larger (also negative) displacement. This new system of absorption lines with

* It seems that the same took place in the spectrum of HR Del (1967).

a long duration is produced by the principal envelope, see below. In this connection we give Table III, which contains some data about the pre-maximum and the principal spectra of seven novae. Table IV contains some information about absolute visual magnitudes, temperature and radii of eight Novae at light maximum.

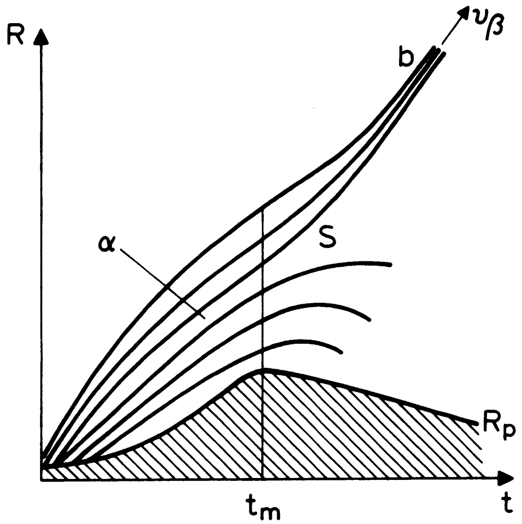

Fig. 7. Expansion of a nova and subsequent contraction of its 'photosphere' R_P: a = a very extended 'reversing layer' of the nova, b = its principal envelope.

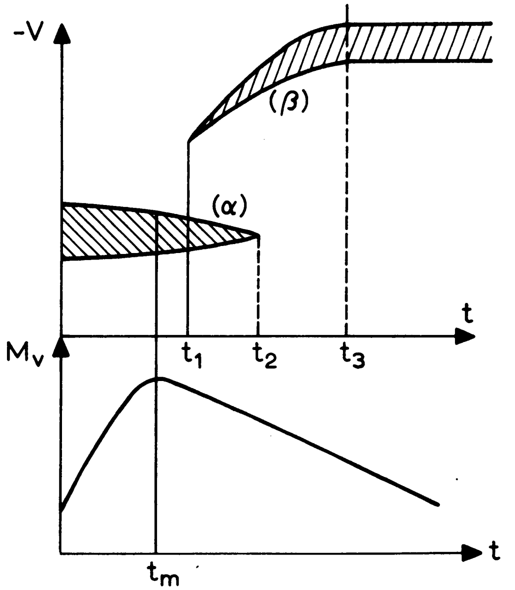

Fig. 8. The transformation of the pre-maximum spectrum (system α) into the principal spectrum (system β). The width of the systems characterizes their strength.

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TABLE III

Some principal physical characteristics of novae

Nova	Pre-maximum spectrum			Principal spectrum	
				Velocity decuded from the absorption principal spectrum in km s^{-1}	
	The spectral type of nova at first moment of observation	Spectral type at light maximum	Velocity deduced from the pre-maximum spectrum at light maximum in km s^{-1}	At first moments of its appearance	At end of evolution of principal spectrum
GK Per 1901	B9p	A0	− 713	− 1308	− 1500
DN Gem 1912	A5	F0	− 452	− 772	− 830
V 603 Aql 1918	A0	A5	− 1280	− 1380	− 1720
V 476 Cyg 1920	A0	A2	− 507	− 725	− 820
RR Pic 1925	F2	gF8	− 97	− 298	− 410
DQ Her 1934	B5p	cF0	− 180	− 310	− 394
CP Lac 1934	B9p	gA2	− 1144	− 1316	− 2527

TABLE IV

The radii of the photospheres R_p of novae at light maximum and in their 'normal' state, a few decades after light maximum

Nova	Light maximum				'Normal' state		
	M_{vis}	Spectrum	Temper-ature	$R_p/R_\odot$	M_{vis}	$R_p/R_\odot$	
						$T=40000°$	$T=10000°$
V603 Aql 1918	$-9^m_.2$	A5	8500°	320	$2^m_.7$	0.33	1.2
V476 Cyg 1920	−9.6	A2	9700	320	4.5	0.14	0.52
DN Gem 1912	−7.5	F0:	7500	185	3.7	0.21	0.76
DQ Her 1934	−5.6	cF0	7500	95	8.1	0.03	0.10
CP Lac 1936	−9.3	gA2	9700	280	3.9	0.19	0.69
GK Per 1901	−8.5	A0	10700	170	4.8	0.13	0.46
RR Pic 1925	−7.4	gF8	5800	300	4.7	0.13	0.48
CP Pup 1942	−9.1	A5	8500	310	8:	0.03	0.10

Even at the first moment of its appearance the principal spectrum is 'detached' from the pre-maximum spectrum. This process of replacement of the pre-maximum spectrum by the principal spectrum takes place during an interval Δt_0 of the order of a few days. Spectroscopic observations give the impression that the increase of strength of absorption lines of the principal spectrum proceeds at the expense of the simultaneous decrease of the strength of absorption lines of the pre-maximum spectrum, see Figure 8. Moreover, from the spectrophotometric analysis of DQ Her (Antipova, 1971), it follows that the mass of the *principal envelope* (which is mostly due to hydrogen) was equal at the time t_3 to the mass of the gases which were responsible for the pre-maximum spectrum of DQ Her at light maximum t_m. These are all reasons to conclude that, immediately after light maximum, the gases responsible for the pre-maximum spectrum are accelerated by a force P and, after an interval $\Delta t_0 \simeq t_3 - t_m$, they produce the *principal envelope* with the same mass but moving with a larger expansion velocity.

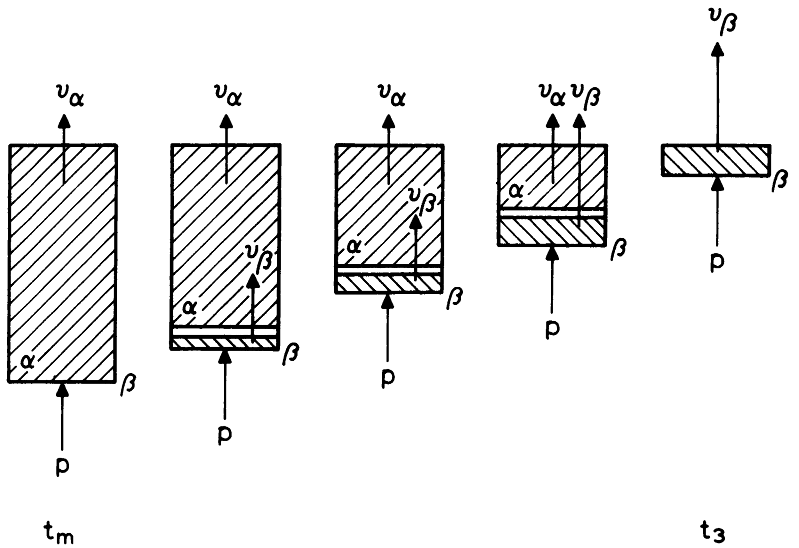

Fig. 9. This figure explains the $\alpha \to \beta$ transformations shown in Figure 8. P is the force which is responsible for these transformations.

Figure 9 shows this process of $\alpha \to \beta$ transformation. From Figure 9 it follows that as a result of the $\alpha \to \beta$ process the density of gases in the β-layer must be higher than that in the α-layer. This is confirmed in the papers of Antipova (1969, 1971).

In accordance with the model shown in Figure 7, it follows from Figure 8 and 9 that already at light maximum the envelope of the nova which is responsible for the pre-maximum spectrum is transparent in the frequencies of the continuous spectrum. This is confirmed by direct computations carried out for DQ Her. The hydrogen abundance in the envelopes of novae* is quite normal (see Section 6) and the continuous absorption of radiation in these envelopes is mostly due to neutral hydrogen. The analysis of DQ Her at the moment t_m permitted the calculation of the number of excited hydrogen atoms in the envelope (Antipova, 1971). This in its turn permitted the determination of the optical depth τ_c of the envelope in the frequencies of the continuous spectrum at $\lambda \simeq 5000$ Å. The results of the computations, not yet published, are: $\tau_c \simeq 0.05$.

It is very important to note that the velocity of the motion of gases which produce the principal absorption spectrum practically coincides with the velocity which char-

* Here we have in mind the envelopes which create the pre-maximum and the principal spectra.

acterizes the expansion of the envelope, i.e., the nebulosity around the nova, observed several years after light maximum for the nearest novae. This velocity is usually calculated from the half-widths of the forbidden and permitted emisson lines of the principal spectrum (for this purpose the lines $\lambda\lambda$ 6300 Å, 6363 Å [O I], N_1, N_2, [O III] and many others are used). Thus the principal envelope which contains the main mass ejected by the nova is formed only *after* light maximum!

Now let us consider the nature of the force P which produces the acceleration of gases inside layer α; see Figure 9. It was concluded in the papers of McCrea (1937) and Mustel (1957) that this force is the radiation pressure. However subsequent and improved information on the luminosities L of novae at light maximum and on the masses $\mathfrak{M}$ of the principal envelopes produced very serious difficulties in the radiation pressure hypothesis (Mustel, 1962). In fact knowing from observations the magnitudes of L, $\mathfrak{M}$ and Δt_0, we can calculate the maximum increase of the expansion velocity ΔV of the envelope which might be produced by the radiation pressure. It appears that this increase of velocity ΔV is three or four orders less than the difference $\Delta V_{\mathrm{obs}} = V$ (principal spectrum) $- V$ (pre-maximum spectrum) which follows from observations. It is also necessary to keep in mind that the line-emissions in the spectra of novae during the time of the $\alpha \rightarrow \beta$ process are usually rather weak (for example, DQ Her). Therefore the radiation pressure connected with the emission lines in the spectra of novae (even in the Lα line) must be also negligibly small.

In connection with all these difficulties, Mustel (1962) has suggested that the force P is due to the high energy particles which are accelerated in the immediate vicinity of the 'photosphere' of the nova (below region S in Figure 7) and exert a corpuscular pressure upon the internal parts of the expanding layer α; see Figure 9. The existence of such an intense acceleration of particles is expected from the following considerations. In fact at light maximum the 'photosphere' of a nova stops expanding, but no non-displaced absorption lines are observed at this time in the spectrum. This shows that the outer parts of the photosphere which are expected to produce the non-displaced absorption lines are in a state of very strong turbulence. But with the presence of strong magnetic fields (see Section 8 and the Addendum) these motions may create phenomena similar to solar chromospheric flares. Here we wish to point out the fact that in many cases the principal envelope of a nova (for example CP Lac, V 603 Aql, RR Pic, etc.) is accelerated even after the end of the $\alpha \rightarrow \beta$ process. This seems quite natural and shows that the process of the intense acceleration of particles may take place for a rather long period of time after the moment t_m. In this connection we may point out that the presence of very intense, chaotic, supersonic gas motions in the *photospheres* of novae after the moment t_m follows from the absence of a Balmer jump in their spectra. In fact the photospheres of novae with strong supersonic motions are expected to be in an isothermal state and this must lead to the absence of the jump at the limits of series (Mustel, 1951). The problem of acceleration of protons in the atmospheres of novae after light maximum is considered also in the paper of Rumjantsev (1973).

In conclusion we shall try to explain why, just after light maximum, the outer layers

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of the expanded photosphere of a nova acquire such an unusual state. It seems that it is due to the fact that by light maximum the process of expansion of the shell accreted onto the surface of the white dwarf is practically finished, but the strong *local* non-stationary phenomena continue to play a very important role. This is manifested in the phenomena of the ejections of gas clouds from the relatively deep layers of the photosphere of a nova after light maximum.

7. The Evolution of the Nova after Light Maximum. The Chemical Composition of the Ejected Envelopes

The principal envelope ejected by the star is expanding; the velocities of this expansion for different novae are different, from approximately 200 km s^{-1} to 2500 km s^{-1}. The density of gases in the principal envelope continuously diminishes and after some time the spectrum created by the envelope (the absorption and emission lines) becomes a purely emission spectrum. According to available data the source of emission of the envelope after its ejection is the radiation from the nova itself, which is absorbed by the envelope. This conclusion follows from observations of the radio emission of novae after light maximum, which confirm the thermal origin of radio waves from the envelope. The radio-temperature of the envelope is close to the temperature of the nova itself.

For the nebular stage of novae the analysis of the physical properties of the principal envelope proceeds on the base of those methods which are worked out mainly in application to the gaseous nebulae. Therefore we shall not discuss the details of this analysis.

After the ejection of the principal envelope, the nova begins to contract and to increase its temperature. The process of contraction of the star after light maxmum was studied recently by Nariai (1974).

After light maximum the photosphere of the nova is very unstable (see above) and this explains the numerous, irregular, sometimes quasiregular (V 603 Aql) fluctuations in the brightness of the star. Moreover, almost immediately after light maximum a continuous ejection of gases from the nova sets in which produces the so-called diffuse-enhanced and orion spectra of the star (McLaughlin, 1960). The velocities of the clouds which constitute the continuous outflow of gases is usually 2-3 times higher than the velocity of the expansion of the principal envelope. The origin of this outflow is not quite clear, but it seems that it does not play any important rôle in the evolution of the nova. This outflow also cannot play any important rôle in the $\alpha \rightarrow \beta$ process of the formation of the principal envelope (see Section 6). For instance the diffuse-enhanced spectrum of DQ Her appeared when the pre-maximum spectrum of the star had been completely transformed into the principal spectrum. Later the intensity of the diffuse-enhanced spectrum became much stronger, but the displacement and the intensity of the principal spectrum remained practically constant for a long period of time. The displacement began to increase only a month later, after light maximum. The computations based on the difference between the displacements of the principal spectrum and the diffuse-enhanced spectrum show that by this time the gas clouds constituting the diffuse-enhanced spectrum were able to overtake the principal envelope and to accelerate it (Mustel, 1950).

At a certain moment after light maximum, some relatively *narrow emission lines* of hydrogen, helium and of other elements appear in the nova spectrum; this fact shows that a quite new 'shell' is being formed around the star. After some time (usually a few decades after light maximum) the emission lines of the principal spectrum disappear and we can see only the continuous spectrum and these narrow emissions. A general opinion, confirmed by observations, is that these emissions are due to the disks around novae (see Section 5), the existence of which is confirmed by the analysis of Kraft (1959); see also Figure 6. We may recall that these disks are the result of the interaction of two stars in a close binary system (the jets of gases from the surface of the cool star towards the white dwarf). Some problems on the physics of these disks are discussed in the review of Mumford (1967) and Gorbatsky (1974).

Now a few remarks about the principal characteristics of novae a few decades after light maximum. From this time on their brightness is practically the same as before the explosion, their temperature is relatively high, on the average higher than 20000°, and their dimensions are small (see Table IV).

In conclusion we shall discuss briefly the problem of the chemical composition of the envelopes ejected by novae. The most favourable moment for the analysis of novae *absorption* spectra is the light maximum*, when the emission is rather weak. The analysis shows (Mustel and Antipova, 1971; Antipova, 1974), that the chemical comsition of the outer shells of novae has the following properties: (a) the *relative* abundance of metals in the shell is practically the same as the relative abundance of these elements in the atmospheres of the 'normal' stars of the main sequence; (b) the ratio of abundances of C, N and O to the abundances of metals in the shells of novae is considerably higher (10–100 times) than the same ratio in the envelopes of 'normal' stars; see Figure 10. The relative abundance of C and N atoms in the envelopes of novae may be obtained also on the basis of the following fact. Immediately after light maximum the spectra of certain novae contain strong CN-absorption bands which are practically absent in the spectra of 'normal' stars of the equivalent spectral class. The analysis also gives a very high abundance of CN in the principal envelope of novae (Antipova, 1969); (c) the results of Pottasch (1967), based on the analysis of the emission (nebular) spectra of novae and a comparison of these results with the above-mentioned results of Mustel and Antipova confirm the presence of anomalously high abundances of O, C, and N in the envelopes of novae. In addition they indicate a quite 'normal' abundance of hydrogen in these envelopes. All these results are in agreement with the theoretical computations of Starrfield *et al.* (1972), about which we spoke in Section 5, and thus they confirm the idea that during the explosion of a nova we are dealing with a violent instability in the shell which is accreted onto the 'surface' of the white dwarf.

* The gases which at light maximum produce the nova pre-maximum spectrum and the principal spectrum are practically the same, see Section 6.

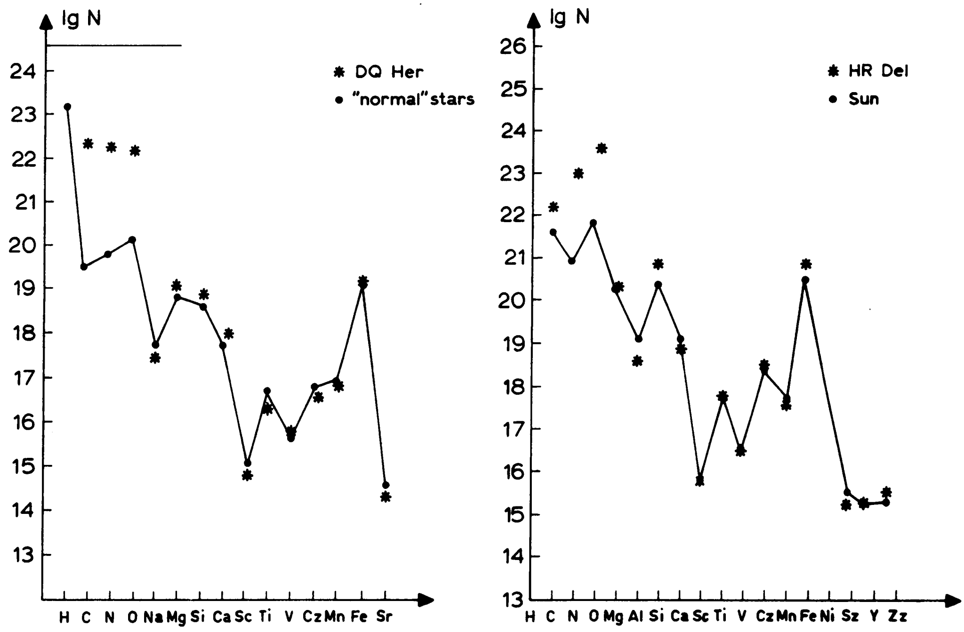

Fig. 10. Comparison of the relative chemical abundances of the envelopes of novae (asterisks) with the relative abundances of the atmospheres of main sequence stars and the Sun (dots).

8. The Structure of the Principal Envelopes

Direct photographs of the principal envelopes, the nebulosities around novae, as well as spectroscopic studies show that very often these nebulosities have an axial or spherical symmetry. (For GK Per such a symmetry is absent and it seems that this is connected with the fact that the period of revolution of the stars in this binary system is anomalously long, of the order of 2 days.) The following very important properties of the envelopes are connected with the axis of symmetry PP: (a) a general prolateness of the envelopes of certain novae *along* the axis PP; see the photographs of the envelopes around DQ Her and T Aur in the papers of Mustel and Boyarchuk (1970), Boyarchuk (1970) and of Weaver (1974), especially Figure 16 of this last paper; (b) the so-called polar condensations; (c) equatorial 'belts' (or 'rings') which are characterized by enhanced emissions in the forbidden lines 6548 and 6584 Å of [N II]. For DQ Her and V 603 Aql all these features are shown schematically in Figure 11 taken from the paper of Mustel and Boyarchuk (1970). The presence of equatorial belts around other novae is confirmed in the papers of Hutchings (1972) and Malakpur (1973b).

First let us consider the *polar condensations*. It is necessary to point out a very important fact: their time-evolution is not connected with the evolution of the equatorial belts. Besides, inside the envelopes, the polar condensations are separated from the equatorial belts by a very large distance. Here we may notice that in some cases the polar condensations are very small, 'star-like' objects; see Figure 4 in the paper of Mustel and Boyarchuk (1970). This Figure shows one very small condensation in the nebulosity around Nova V 603 Aql; another condensation was considerably weaker, but spectroscopic observations confirm its existence (Wyse, 1939).

From all that has been said it may be concluded that the origins of polar condensations and equatorial belts are practically independent.

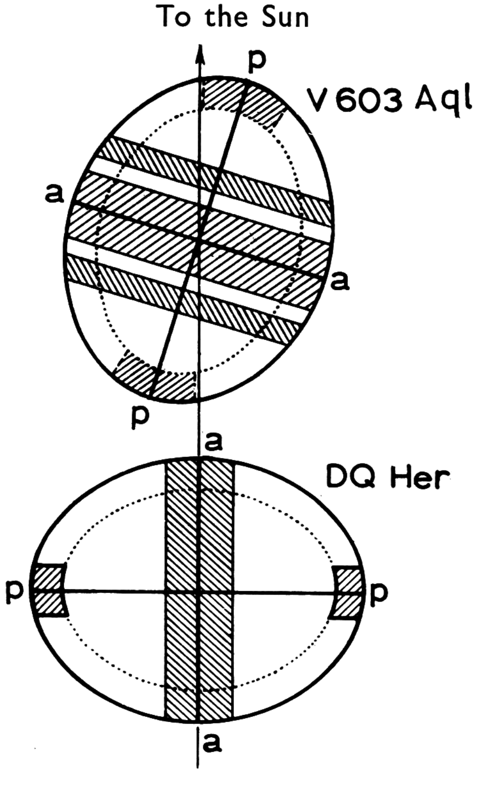

Fig. 11. Morphological models of the principal envelopes of the novae V 603 Aql and DQ Her: PP = the 'polar' axis, aa = the 'equatorial belt'.

The analysis of V 603 Aql showed that in its 'integral' spectrum the polar condensations produced a 'bifurcation' of emission lines. It seems that the same takes place for many other novae, though the generalization of this rule must be checked by subsequent investigations.

In the papers of Mustel (1956, 1958) the origin of polar condensations is connected with *strong magnetic fields* of a *dipolar* type*. In the presence of such a field the least retardation of the plasma ejected from a nova is along the magnetic axis of the star, where there is the strongest convergence of the magnetic field lines. Thus the amount of gas ejected from a nova in these directions is expected to be the greatest.

There are additional considerations which speak in favour of the presence of strong

* The magnetic field lines of this component may be partly entangled, see Mustel (1958).

dipolar magnetic fields in novae: (a) there is a quite natural explanation of the observed prolateness of the nebulosities around some novae. According to the considerations presented above the average retardation of the moving plasma in the directions perpendicular to the magnetic axis *PP* is larger than in the polar directions (we speak here only about those parts of the envelopes which are free of equatorial belts); (b) using the monochromatic luminosity L_λ of a nova and its temperature for various moments before light maximum obtained from observations, we may compute the 'photospheric' radii for these moments (Mustel 1948). These calculations show that the average velocity of the 'photospheric' gases of novae before light maximum is much higher than the parabolic velocity, estimated for $M \simeq M_\odot$. Nevertheless the photospheric gases 'remain' with the star (see Figure 7 of this paper). Again this fact may be explained naturally if we admit strong magnetic fields for novae (Mustel, 1956, 1958).

Let us consider now the problem of the origin of the 'equatioral belts' in the envelopes ejected by novae. Mustel (1956, 1958) again attempted to explain their origin from the point of view of strong magnetic fields in novae using the continuous ejection of gases from these stars after light maximum, the ejection which produces the diffuse-enhanced and orion spectra of novae (see Section 7). It is suggested that this ejection of gases from a nova is directed by its magnetic field towards the equatorial plane, similar to the solar corona at the minimum of solar activity. It is true that there is a difficulty in this model. The emission bands in the spectrum of V 603 Aql which correspond to the equatorial belts appeared a little before the appearance of the diffuse-enhanced spectrum of this star. However, unlike DQ Her, this nova was a very fast one and it is not excluded that the continuous ejection of gases from it originated at light maximum or even earlier, but during the first moments the amount of ejected gas was insufficient to produce noticeable absorption lines of the diffuse-enhanced spectrum.

Now let us discuss another explanation of the equatorial belts in the principal envelopes of novae. This explanation was given almost simultaneously by Hutchings (1972), Sparks and Starrfield (1973), Gorbatsky (1974) and Weaver (1974). These authors connect the equatorial belts and some other regularities in the structure of the principal envelopes with the presence of the emitting 'disk' which is observed around novae, sometimes after light maximum (Section 7). It is supposed that before the explosion of the star this disk is *rather massive* and therefore immediately after the explosion* the outer layers of the nova (which after light maximum become the principal envelope) suffer a certain retardation. Therefore we may expect that in the plane of the disk the outward gas velocities in the principal envelope should be smaller than in the perpendicular directions. This will produce the prolateness of the envelope along the polar axis. Besides the principal envelope in its equatorial plane will contain some additional mass of gases which earlier constituted the disk of the nova. All this may produce the phenomena which we identify as the equatorial belt.

However, all these suggestions are subject to certain difficulties. For example let us

* It is expected that the size of the disk is much smaller than the size of the nova even during the first stage of its expansion.

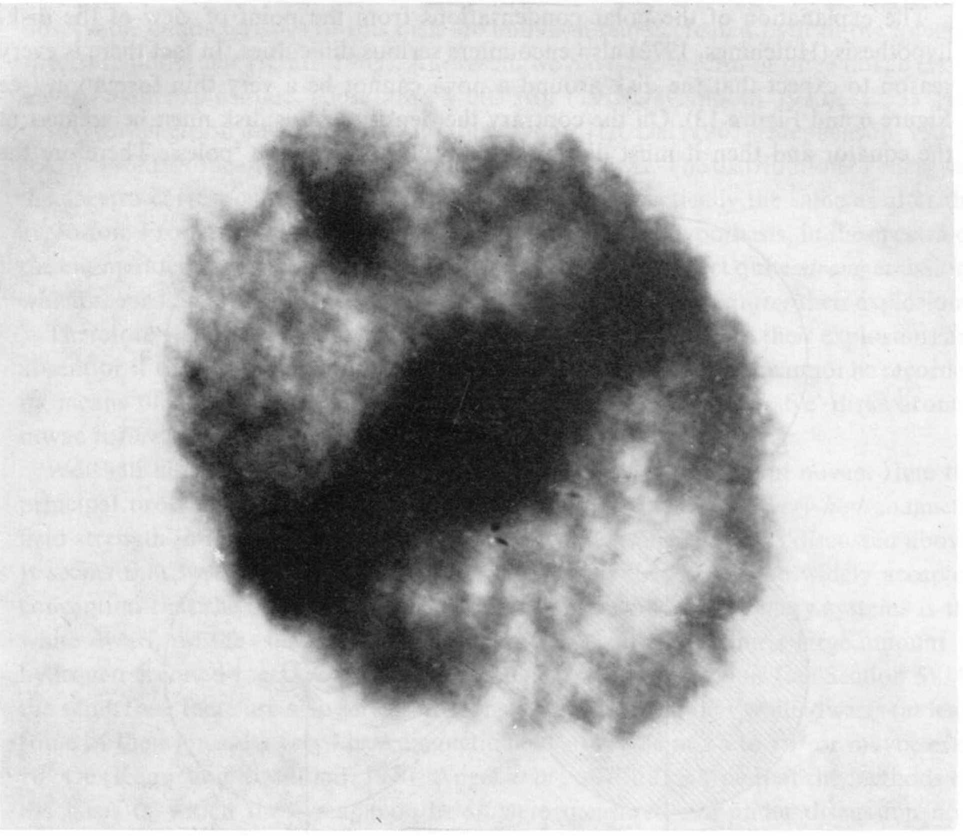

Fig. 12. The photograph of the envelope of DQ Her in the spectral region $\lambda\lambda$ 6400–6700 Å taken by W. Baade in 1956.

consider a photograph of the nebulosity around DQ Her (Figure 12) taken in 1956 by W. Baade in the region $\lambda\lambda$ 6400–6700 Å (see Mustel and Boyarchuk, 1970). From the point of view of the hypothesis under consideration the equatorial 'belt' on this photograph was produced by the 'disk' around the nova. At the same time we see that the prolateness of the envelope along the axis *PP* is approximately the same within the limits of the belt and outside the belt. The same conclusion may be made on the basis of the photograph of the principal envelope of DQ Her taken in 1973 and presented in Figure 16 of the paper by Weaver (1974). In this photograph we see a narrow 'equatorial belt' which should be identified with the equatorial belt on our Figure 12*. In addition we see two narrow parallel belts at relatively high latitudes. The existence of *three* belts is not foreseen in the papers of Hutchings, Sparks and other investigators. Besides the prolateness of the envelope (between the belts) has no relation to these three belts.

* The difference between the two figures is due to the differences in the resolution of the corresponding photographs.

The explanation of the polar condensations from the point of view of the disk-hypothesis (Hutchings, 1972) also encounters serious difficulties. In fact there is every reason to expect that the disk around a nova cannot be a very thin formation (see Figure 6 and Figure 13). On the contrary the density of this disk must be greatest at the equator and then it must diminish smoothly towards the 'poles'. Therefore the

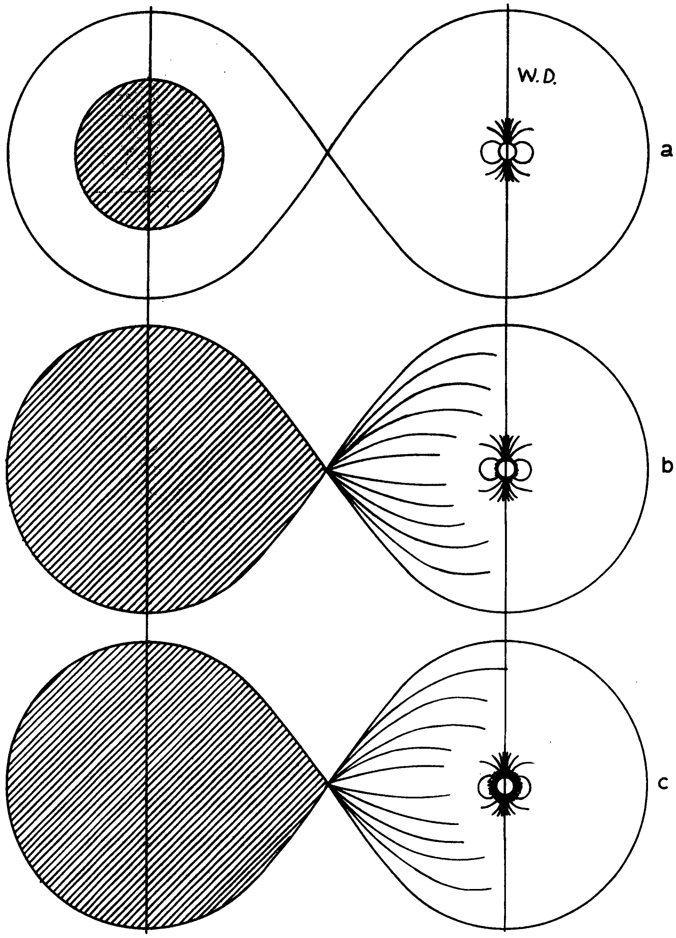

Fig. 13. Diagram explaining the origin of the strong magnetic fields in novae.

latitudinal extension of the polar condensations is expected to be very large. At the same time this contradicts the observations which show (see above) that these condensations in the case of V 603 Aql are very small and star-like. Only very strong magnetic fields can explain all these phenomena.

Let us continue our discussion. The starting point of the hypothesis under consideration is the admission that immediately *before* the explosion of a nova the emitting disk around the star does exist and it is rather massive. On the other hand the principal

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observable characteristics of this disk are emission bands created by it in the integral spectrum of the star (Kraft, 1963). At present we have the spectra of three novae taken before their explosions. These are: V 603 Aql (1918), (Cannon, 1920); V 533 Her (1963) (Stephenson and Herr, 1963); Götz (1965); HR Del (1967) (Stephenson, 1967); (Götz, 1968). None of these 5 spectra show *line-emissions*. The distribution of energy in the spectra corresponds to rather high temperatures, practically the same as after the explosion. From the point of view of the above mentioned hypothesis, in the spectra of the enumerated novae before their explosions, we should expect quite *strong* emissions which according to Kraft (1963) characterize the spectra of novae *after* their explosions.

Therefore we may conclude that the disks around novae before their explosions are absent or if they exist then due to their small masses the emissions cannot be recorded by means of objective prisms. In any case the hypothesis of 'massive' disks around novae *before* their explosions is premature.

We shall discuss again the hypothesis of strong magnetic fields in novae. Here the principal problem is the origin of these strong magnetic fields. A *very high* magnetic field strength in novae follows from all the facts and considerations discussed above. It seems that we should connect the origin of these fields with the widely accepted conception that the central body of the main hot star in novae binary systems is the white dwarf, on the 'surface' of which there is a shell containing a large amount of hydrogen accreted together with other elements from the cool star (see Section 5). At the same time there are also serious reasons for considering that white dwarfs (at least some of them) possess very large magnetic field strengths of up to 10^6 or maybe even 10^7 Oe (Kemp and Swedlund, 1970; Angel *et al.*, 1972). It is true that the methods on the basis of which these magnetic fields were measured are under discussion now (see Angel *et al.*, 1972, and especially Angel *et al.*, 1974), but the very fact of existence of strong magnetic fields in some white dwarfs is not disputable.

Let us consider now Figure 13 which shows the time-evolution of a nova binary system. The first diagram '*a*' corresponds to the initial stage of the evolution when the system is 'detached' because the size of the cool star is less than the Roche surface. In 'b' the size of the cool star is equal to the size of the Roche lobe and there is already an outflow of gases towards the white dwarf. Since the temperature of the cool star is relatively low, the neutral hydrogen atoms which pass through the Lagrangian point L_1 will easily enter the region of the magnetic field of the white dwarf*) and will move towards its surface. Close to the surface the hydrogen will be completely ionized and will form together with other elements shell S of the white dwarf, as shown in diagram 'c'. This shell will also have a strong magnetic field.

Thus, when the gas pressure and accordingly the temperature at the bottom of this shell S become sufficiently high, a thermonuclear explosion will take place, accompanied by a subsequent expansion of the shell which 'acquired' even before the explosion a strong magnetic field. The presence of such a field explains many facts about which we have spoken earlier.

* The study of the Earth's envelope shows that ionized atoms can also enter its magnetosphere.

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Before we continue our discussion we shall mention again the principal envelope around V 603 Aql, the prolateness of which at the equator is 'replaced' by an extended equatorial belt (Weaver, 1974). It seems that these equatorial regions are due to the 'corpuscular' pressure of clouds which produced the *orion* spectrum of this nova. This spectrum was relatively strong, showed very high Doppler displacements (velocities up to 4500 km s^{-1}) and contained strong absorptions due to the N-atoms in different stages of ionizations (Wyse, 1939). Correspondingly the *emissions* due to the N II-atoms in the spectra of the equatorial belt of the nova were very strong and persistent over a relatively long period of time (Wyse, 1939; Mustel and Boyarchuk, 1970).

It is quite natural that the best method to confirm the presence of strong magnetic fields in novae might be the analysis of the Zeeman effects in the spectra of old novae a few decades after their explosion. However this method can hardly give anything definite. In fact the analysis of old novae themselves (not their principal envelopes) shows that their spectra contain only two components: the emission bands produced by the disk and the continuous spectrum between these emission bands.* Let us consider them both.

The bright bands emitted by the disk are connected with the gases moving towards the main star from the cool star which does not possess a strong magnetic field. Also, the mean radius R_E of the principal emitting region in the disk is several times larger than the radius of the nova itself. For V 603 Aql this radius R_E is five times smaller than the radius of the nova (Mustel and Boyarchuk, 1965). If the magnetic field strength H is proportional to R^{-3} then the magnitude of H in the shell** would be approximately 100 times smaller than on the 'surface' of the star. Thus the analysis of Zeeman effects in the relatively wide emission bands of the spectra of old novae can give nothing. A study of the linear polarization in the emission bands of the spectra of V 603 Aql, carried out in 1964 by Mustel and Boyarchuk did not show any noticeable polarization effects (not published).

The circular polarization in the *continuous* spectrum of V 603 Aql was studied by Nikulin *et al.* (1971). They did not find any noticeable effects in this spectrum. However we have already mentioned that the analysis of stellar magnetic fields on the basis of circular polarization in the continuous spectra of stars is now under discussion.

In this connection we may add the following considerations. As we have already mentioned (see Section 6), the outer layers of the photospheres of novae immediately after light maximum are in a state of strong chaotic gas motions and these motions must disturb the *outer* magnetic fields of novae, directly observed. The recovery of a coherent magnetic field (say, of a dipolar type) may take a long time, maybe even thousands of years† or more.

* The 'old' nova GK Per also shows the absorption spectrum of the cool component of the system, a star of spectral class K2 IVp.

** This would be true if the shell were an outer part of nova which is almost excluded (see above).

† These coherent magnetic fields may be recorded only for the novae with relatively thin outer shells; see the Addendum to this paper.

In conclusion to this section we shall make a few remarks on the origin of the infrared radiation from novae which is produced by the dust component around these stars (Geisel *et al.*, 1970). The first very important problem here is the localization of this component in space. The following fact may help to solve this problem. The strongest infrared radiation from the nova FH Ser was observed during the secondary, very deep minimum in brightness. This fact suggests that a very fast decrease of the thermal radiation from the nova during this period might prevent the destruction of the dust particles. In this connection we may mention that DQ Her had practically the same light curve with a deep minimum in April, 1935. In the spectra of this star during this minimum a weakening of the long wavelength 'halves' of the emission bands responding to the receding hemisphere of the principal expanding envelope was recorded. Stratton (1945) suggested that this phenomenon was due to the very fast appearance of *dust particles* in the cavity between the star itself and the principal envelope. In this case we were able to see only the emission bands created by the approaching chemisphere of the envelope whereas the receding hemisphere was hidden by dust. A similar phenomenon in the emission profiles of FH Ser though not so strong was described by Hutchings and Fisher (1973). Thus similar light curves of both Novae and similar spectroscopic phenomena allow the suggestion that the region of the strong infrared radiation from all novae lies inside a sphere of radius equal to the internal radius of the principal envelope.

The processes of the sudden appearance of dust and the energetics of all these processes require further analysis.

Addendum

Very soon after the end of the Symposium the author of this Addendum became acquainted with the recent results of measurements of the linear and circular polarization of radiation from DQ Her. These measurements were carried out independently by two groups of investigators, Nather *et al.* (1974) and Kemp and Swedlund (1970, 1974).

These measurements established in the optical region of the spectrum from this nova the presence of polarization, the degree of which periodically changes with time. The periods of changes of polarization are 71 and 142 s. The first period corresponds to the period of the light oscillations of DQ Her found by Walker (1957), which were connected earlier by many astronomers with some pulsations of the nova, see also Beer (1973). However, according to the just mentioned communications, the interpretation of these periodic light variations is quite different. It is concluded that DQ Her is *rotating very rapidly* and that the period of this rotation is equal to 142 s. It is considered that the origin of the linear and circular polarization is the same as in the pulsar NP 0532 inside the Crab nebula, i.e. the synchrotron radiation which is due to the *strong magnetic field* of DQ Her and to the streams of relativistic particles from this star. These conclusions, which are based on direct polarization measurements, confirm completely the models of novae and of their principal envelopes which are presented in Sections 6 and 8 of this paper.

Let us consider briefly some very important problems connected with these new results:

(a) In connection with the polarization measurements of DQ Her, there is every reason to assume that the beams of synchrotron radiation from the nova are more or less perpendicular to its rotational axis and that this axis is perpendicular to the line of sight towards the nova. This model is in full agreement with the model of DQ Her presented in Figure 11, if we assume that the rotation axis of the star coincides with its magnetic axis. If that is so, then the source of the beams of synchrotron radiation from DQ Her are the *equatorial* regions of the nova and not its poles. This hypothesis seems to be more reasonable than the usual hypothesis accepted for the pulsar NP0532 and other pulsars, which supposes that the sources of synchrotron emission are the magnetic poles. In fact all the solar activity (including ejections of high energy plasma) is connected with the regions *close to the* solar *equator of rotation* and not with the magnetic poles. This activity must be especially pronounced for such very rapidly rotating stars as the classical pulsars and the stars similar to DQ Her. For the radius of DQ Her on the order of 0.05 $R_\odot$ and the period of 142 s, the velocity of rotation at the equator is on the order of 1000 km s^{-1}. The same considerations are valid for pulsars.

(b) The second question is: why are the polarization effects so clear for DQ Her and absent, for example, for V 603 Aql? There are two natural explanations of this fact:

(1) From Figure 11 it follows that the axis *PP* for V 603 Aql is directed approximately towards the observer and thus the beams of the synchrotron radiation, if they exist, should pass by the Earth.

(2) It follows from Table IV, that the absolute magnitudes of novae in their 'normal' state (between the explosions) have a very large dispersion. We may connect this fact with the hypothesis that the mass of gases which is transported from the cool star to the surface of the white dwarf is different for different novae and that it reflects a different level of evolution of the stars in the binary systems of novae. If this is so then the more massive shells of the white dwarfs (which correspond to brighter novae) must exert a strong disturbing influence on the generation of the relativistic particles, since, as we may speculate, this generation is produced by the white dwarf *itself* and is not connected directly with its hydrogen-rich shell. Thus we may expect the strongest polarization effects for such absolutely weak objects as DQ Her (see again Table IV). These considerations are in agreement with the fact that the sufficiently clear rapid periodic oscillations of light are found for DQ Her and are absent for brighter novae.

The discovery that novae possess the same properties as classical pulsars is a very important confirmation of the general conclusion made by Mustel (1970b) that supernovae and novae are similar objects and that the principal difference between them is mostly in the energetics of the corresponding phenomena. This discovery confirms also the hypothesis according to which all supernovae are double star systems and at least one of the stars in the system is a 'normal' neutron star (Mustel, 1970b). The explosion of the very rapidly rotating star produces the pulsar phenomenon. On the other hand it turns out that there is a very close similarity between the 'pulsar phenomena' in supernovae and in novae but there is no collapse in the case of novae. Therefore there is no need to introduce a hypothesis of stellar collapse for supernovae.

Since novae possess strong magnetic fields we have every reason to expect that the similar objects, supernovae before their explosions, also have very strong magnetic fields and this naturally explains the origin of weak magnetic fields in supernovae remnants. It is expected that these magnetic fields are due to the very strong internal magnetic fields of Supernovae themselves (Mustel, 1970b).

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DISCUSSION

V. G. Gorbatskij: I should like to make some remarks on the influence of a disc on the main envelopes of novae. There are two kinds of discs:

The disc around a white dwarf has small dimensions and its mass is of the order of 10^{-9} to $10^{-10}\,\mathfrak{M}_\odot$. Evidently, the presence of such a disc cannot influence the motion of the main envelope having a mass of 10^{-4} to $10^{-5}\,\mathfrak{M}_\odot$.

The disc of circumstellar matter that has been lost from a system during many years is much more massive. Its mass can reach $10^{-5}\,\mathfrak{M}_\odot$. This circumstellar envelope influences the motion of the main envelope considerably, as was shown in *Astrophysica* **8** (1972), 369, and may lead to the elongation of an envelope.

Ya. B. Zel'dovitch: What is the energy of an explosion?

E. R. Mustel: About 10^{45} erg.

Ya. B. Zel'dovitch: Is there any graphite? Graphite does not form when oxygen is overabundant.

E. R. Mustel: The distribution of graphite is unknown. There is plenty of carbon.

Ya. B. Zel'dovitch: Have the disc and the second star got any influence on the envelope?

E. R. Mustel: No, they haven't.

R. W. Gershberg: I should like to note that the time scale of temporal damping in nova light curves is the same as the time scale of R CrB decrease. Maybe, we have here really the same process of grain production in a hot radiation field. Therefore, my question is: what is a characteristic electron density within the envelope near a temporal decrease in a nova light curve?

E. R. Mustel: In general, the density in nova envelopes is about 10^{11} to 10^{13}. But I don't think that this density may totally be attributed to those layers where the dust production takes place.

R. W. Gershberg: Your values for the envelopes, 10^{11} to 10^{13}, are really not too far from the expected densities in R CrB chromospheres.

M. Friedjung: I would like to mention the work of Malakpur (1973, 1974), who found evidence from the Balmer decrement of dust in the envelope of Nova Del. He thinks that the Balmer decrement of all novae is effected in this way. I would also like to say that it is not easy to measure chemical compositions from curves of growth. Far more studies are required.

E. R. Mustel: The curve of growth determinations are made near maximum when there is no emission.

A review was given by Mrs Arhipova at the Sydney I.A.U. meeting.

L. Rosino: What is the ratio of the intensity of the emission lines of He I at λ10830 Å and at λ7065 and λ5876 Å?

E. R. Mustel: The line He I 10830 always is much stronger than He I 7065 and He I 5876. It is the strongest line in the He I spectrum.

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