VI. THE OUTER LAYERS OF NOVAE AND SUPERNOVAE

(Edited by C. de Jager)

Organizing Committee

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https://doi.org/10.1017/S1539299600002264 Published online by Cambridge University Press

THE CHEMICAL COMPOSITION OF THE ENVELOPES OF NOVAE

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Abstract. There are two methods to study the chemical composition of the envelopes ejected by novae: (a) the analysis of the absorption spectra of novae; (b) the analysis of emission lines during the nebular stage.

1. The Absorption Method

It is known that the spectra of novae contain usually absorption and emission components. The strength of the emission is smallest at light maximum: sometimes there is even practically no emission in the spectra of novae at the very moment of light maximum. Therefore, only for this moment we may obtain the most reliable results on the chemical composition.

In order to obtain quantitative results from the investigation of the absorption spectrum, we have to know a mechanism of formation of the line profiles.

Before light maximum the outer layers of the nova undergo an expansion with a relatively high velocity. Therefore, it is expected that this expansion may significantly influence the line profiles. However the size of the envelope of the nova at light maximum is usually much larger than the size of the 'photosphere' at this moment (Mustel, 1945). For example the 'photospheric' radius of DQ Her 1934 at light maximum was about 75 $R_{\odot}$, whereas the radius of the envelope was about 500 $R_{\odot}$ (Beer, 1937). Furthermore, calculations show (Mustel, 1945), that in this case the influence of expansion of the envelope on the profiles of absorption lines is very small.

Now we may expect a certain velocity gradient to exist in the expanding envelope of a nova close to light maximum. This velocity gradient may also influence the absorption lines. There are many papers on this problem (Abhyankar, 1964a, b, 1965; Kubikowski and Ciurla, 1965; Ciurla, 1966). The principal conclusions from these papers are the following: (1) The lines, widened by the velocity gradient are asymmetric. (2) Strong and weak absorption lines have different displacements. (3) The equivalent widths of absorption lines is increased, those of the weaker lines are increased more strongly.

At the same time different observers find that at light maximum the absorption lines of spectra of novae are often relatively narrow and sharp. Moreover, we found that there is no asymmetry in the tracings of DQ Her 1934 and HR Del 1967. Then, the equivalent widths W_{λ} of the lines of DQ Her have been compared with the values of W_{λ} for the same lines in the spectra of ε Aur, the supergiant of the same spectral type (Mustel and Baranova, 1965). It has been found, that the lines of DQ Her are systematically weaker than those in the spectrum of ε Aur, the weaker lines being weakened more strongly, whereas we might expect the opposite effect for the case with a velocity

Contopoulos (ed.), Highlights of Astronomy, 501–508. *All Rights Reserved*

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gradient. Thus, it can be concluded that, at least in some novae, the velocity gradient in the envelope is not too large and does not influence appreciably the profiles of absorption lines. This, of course, does not mean that generally the velocity gradient in these envelopes is absent or very small. It seems that the absorption lines are formed mainly inside some effective level, which has a small thickness in comparison with the thickness of the whole envelope and the velocity dispersion in this particular layer is relatively small.

Thus we may assume that the turbulent motions and the radiation damping (or collisional damping) are the main broadening factors of the absorption lines in the spectra of those novae, where the absorption lines have symmetric profiles.

In such cases the usual method of the curve of growth can be used for the determination of the chemical composition. First of all, it is necessary to choose some model for the atmosphere of the star. Since the novae have a very extended 'reversing layer', we may accept the Schwarzchild-Schuster's model. According to this model the upper layers produce mainly absorption lines whereas the continuous radiation comes from a 'photosphere'.

The first results of the analysis of the chemical composition of the envelopes of novae by means of the curve of growth method at light maximum are published by Mustel and Boyarchuk (1959). The spectrograms of DQ Her with a dispersion of about 36 A mm^{-1}, obtained by G. A. Shajn at the Simeiz Observatory were used for this analysis. It has been found that the relative abundances of C, N and O in comparison to the metals are considerably higher in the envelope of DQ Her 1934, than in the atmospheres of 'normal' stars. At the same time the relative abundances of the metals in the envelope of DQ Her and in the atmospheres of 'normal' stars are prac-

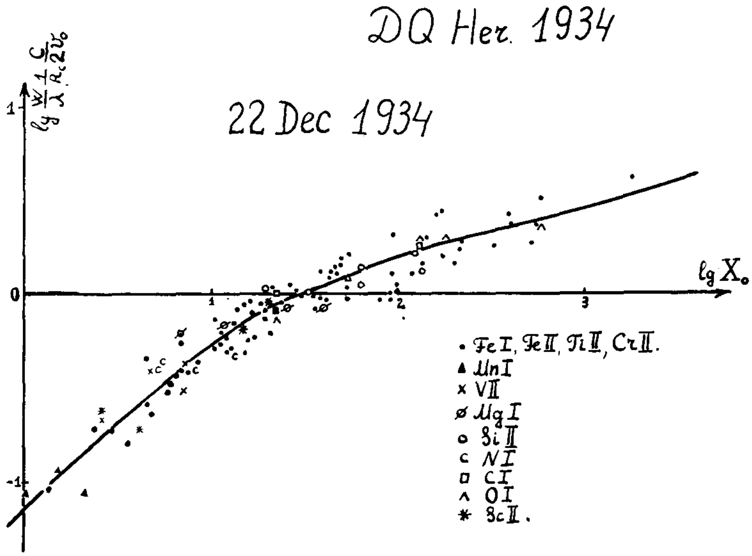

Fig. 1. Curve of growth for DQ Her at light maximum.

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tically identical. Taking into account the importance of the problem of the chemical composition of novae, this analysis was repeated in papers of Mustel and Baranova (1965) and Mustel and Antipova (1971). Improved data on oscillator strengths were used in these papers. Figure 1 shows the curve of growth for DQ Her at light maximum (22 December, 1934). We see, that the scattering of the individual points is small in this figure. This is a direct independent argument in favour of the conclusion about the possibility to apply the method of the curve of growth for the determination of the chemical composition to the envelopes of novae at light maximum.

It is very important to know in such investigations the excitation temperature for different atomic transitions. The usual method here is to plot the dependence of the shift of the multiplets vs the excitation potential. This dependence is normally a straight line and the slope of the line gives the excitation temperature. However, in the case of DQ Her this dependence is not a straight line and we observe the effect of an over-

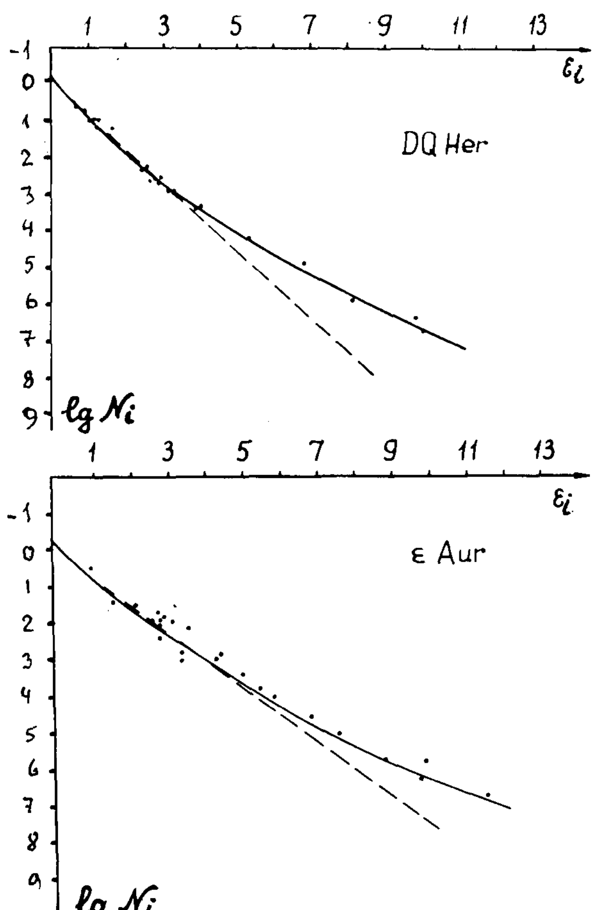

Fig. 2. Relation between number of excited atoms (log N_i) and excitation potential (ε_i) for DQ Her and ε Aur.

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excitation of the levels with high excitation energies (Figure 2, Mustel and Baranova, 1965). It is possible, that this fact has the following explanation. Since the lines with different excitation potentials are formed in different layers of a very extended envelope with a temperature varying with height, the excitation temperature for lines with different excitation potentials has to be different. In particular, this temperature may be relatively high in relatively deep and relatively hot layers. This leads to the effect shown in Figure 2. It is not excluded also that we deal here with some high-temperature cells inside the extended envelope.

It is very important to point out that the dependence shown for DQ Her in Figure 2 is very similar to the one obtained for the supergiant ε Aur, see again Figure 2. Both stars (DQ Her at light maximum and ε Aur) have approximately the same spectral class. This last fact (similarity between spectral classes) was already noted by McLaughlin (1937). This similarity between the two objects is illustrated also by Table I which shows the physical parameters determined by means of the method of the curve of growth for DQ Her and ε Aur. These parameters are approximately identical. Hence the conditions in the envelope of DQ Her were more or less identical to these in the atmosphere of supergiant a of the F-type.

A comparison of the chemical composition of the envelope of DQ Her found by Mustel and Antipova (1971) with the chemical composition for 'normal' stars is shown in Figure 3. We see that the relative chemical composition of the envelope of DQ Her for the metals coincides practically with the 'normal' one. However the abundances of C, N and O in the envelope of DQ Her are two orders higher than the 'normal' ones.

TABLE I

Comparison of physical properties of the envelope of DQ Her and the atmosphere of ε Aur

	DQ Her 1934	ε Aur
v_t	19 km s^{-1}	17.8 km s^{-1}
T_{ex}(0–3 eV)	4500°	4800°
T_{ex}(7 eV)	6300°	6200°
T_i	7000°	6800°
$\lg N_e$	13.36	12.69

The presence of anomalously strong lines of C, N and O in the spectra of DQ Her at light maximum may be considered as a confirmation of this conclusion. The abnormal intensity of these lines cannot be due to an abnormal excitation of atoms of C, N and O, since the absorption lines of other elements which have approximately the same potentials of excitation, (Si II, Mg II) give quite normal abundance.

The appearance of very intense bands of CN just after light maximum in the spectrum of DQ Her confirms also the conclusion about the abnormal abundances of C and N in the envelope of the Nova. The appearance of bands of CN in the spectrum of DQ Her and in the spectra of some other novae immediately after light maximum is very interesting. These bands are practically not discernible in the spectra of usual supergiants of the same spectral types. An investigation by Antipova (1969), carried out on the base of spectrograms of the Mount Wilson Observatory, has shown that the appearance of intensive bands of CN in the spectra of novae is connected with: (1) the abnormally high chemical abundances of O, C and N in these envelopes, (2) a drop of the temperature of the star after light maximum and (3) a very rapid compression of the envelope immediately after light maximum. A transformation of

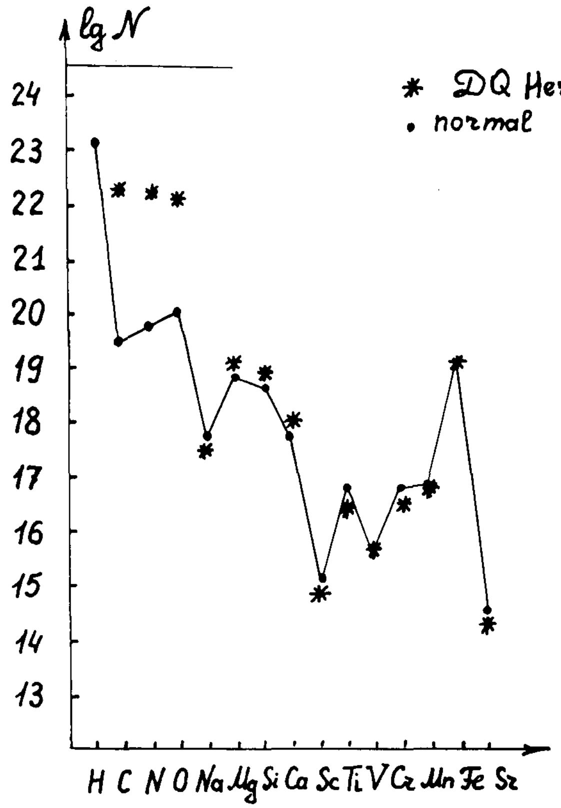

Fig. 3. Chemical composition of the envelope of DQ Her.

the pre-maximum spectrum into the principal one is also connected with this rapid compression of the envelope (Mustel, 1949, 1962).

A similar investigation of the chemical composition of the envelope of HR Del 1967 at light maximum was carried out by Antipova (1974). Spectrograms, obtained in the Haute Provence Observatory and kindly put at our disposal by Prof. Ch. Fehrenbach have been used in this study.

The nova HR Del is a peculiar nova because of its very slow increase and decrease of brightness. The spectrum of HR Del is the typical spectrum of an supergiant F-type with narrow absorption lines. The careful analysis of the profiles oı these lines shows the absence of any asymmetry, which might speak for the presence of a velocity gradient in the envelope.

Half a year has passed between the explosion of the star and the light maximum. The computations show that at light maximum the envelope become so large in comparison with the radius of the 'photosphere', that we may neglect the influence of the expansion of the envelope on the profiles of the absorption lines (see above). Thus, there are reasons to conclude that turbulent motions and radiation damping (or collisional damping) are also the main factors for broadening the absorption lines in the spectrum of HR Del 1967.

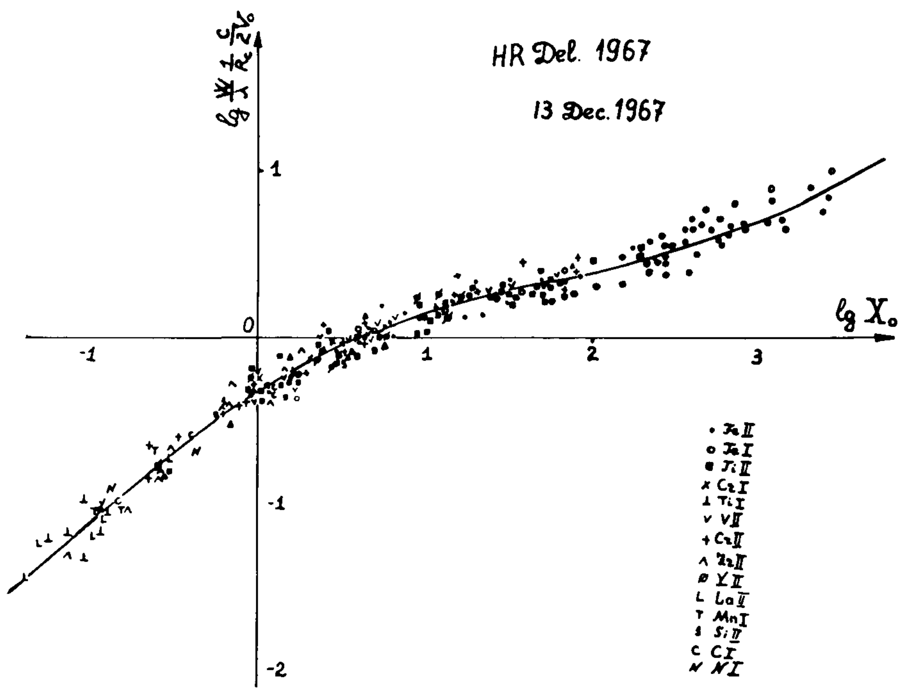

Fig. 4. Curve of growth for HR Del at light maximum.

Figure 4 shows the curve of growth for HR Del 1967 at light maximum (13 December, 1967). The scattering of the points in this figure is very small. This means, that the use of the Schwarzchild-Schuster model is a sufficiently good approximation for the interpretation of the spectrum of this star. It is found again that the excitation temperature in the envelope of HR Del 1967 depends on the excitation potential, similar to the case of DQ Her. This fact was taken into account in the analysis of chemical composition.

Figure 5 shows a comparison of the chemical composition of the envelope of HR Del 1967 with the composition of the solar atmosphere. We may conclude that, similar to the case of DQ Her 1934, the relative chemical composition of the envelope of HR Del

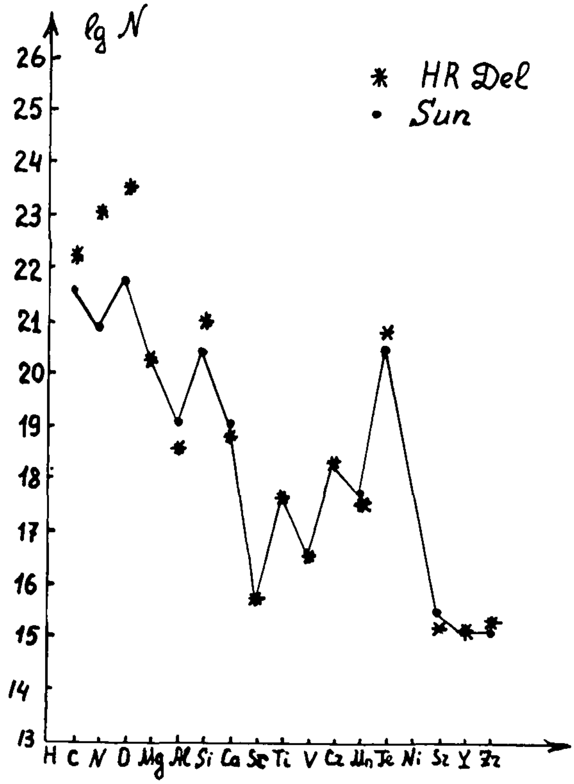

Fig. 5. Chemical composition of the envelope of HR Del.

coincides for the metals with the composition of the solar atmosphere, but the abundances of C, N and O in the envelope of DQ Her exceed the solar abundances by an appreciable factor.

2. The Emission Method

The chemical composition of the envelopes of novae can be determined also by using the emission lines in their spectra during the nebular stage. The methods which are usually used for the determination of the chemical composition of gaseous nebulae, can be also used in this case.

The number density of the atoms of any particular element relative to that of the hydrogen atoms can be determined from the ratio between the energies, emitted in the lines of this element and in the lines of Balmer series. In this case we have to know the ratio between the volumes, which emit in the lines of the element and in the Balmer lines. The evaluation of these volumes is generally the most serious difficulty in the problem of the determination of the chemical composition of the envelopes around novae. In addition, since the degree of ionisation during the nebular stage is rather high, it is necessary to know the temperature of the star, the electron density and the dilution factor.

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TABLE II

Chemical composition of the envelopes of novae determined from the analysis of emission lines (according to Pottasch (1967))

Element	lg *N*		
	RS Oph.	Average five novae	Normal stars (C. W. Allen)
H	12	12	12
He	11.63	11.18	11.16
O	9.81	9.63	8.83
N	9.40	9.70	7.96

The determination of the chemical composition of the envelopes of five novae in the nebular stage has been carried out by Pottasch (1967). It was found, that the abundances of the O and N atoms relative to H is considerably higher, than that in the atmospheres of 'normal' stars (Table II).

The abundances of He, O and N atoms in the envelopes of several novae on the base of emission lines in the nebular stage were determined by Ruusalepp and Luud (1970). They concluded that the abundances of these elements in the envelopes of the novae exceed the normal ones. In addition, they found that the larger the rate of decrease of brightness, the larger is this excess; thus, this excess is less in 'slow' novae than in the 'fast' ones. The authors explained this result by assuming that the fast novae are more evolved objects than the slow ones.

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