

A SPECTROPHOTOMETRIC STUDY OF NOVA LACERTAE, 1936

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ABSTRACT

Nova Lacertae, 1936, was observed with the quartz slitless spectrograph of the Lick Observatory between July 2 and November 21, 1936. Plates obtained on nine nights were chosen for reduction over the spectral region $H\alpha$ to $\lambda 3100$. The intensities of various features were referred to the intensity in 1 Å of the continuum of the star π^1 Cygni at the wave lengths of these features. The results were converted to relative intensities by applying an assumed intensity distribution in the spectrum of π^1 Cygni and by correcting for space absorption. The resulting intensities are shown for the background spectrum in Figure 2 and for the emission lines in Table 2. Figures 3 and 4 give the variations of emission-line intensities with time.

The results are discussed on the basis of the expanding envelope model of the nova. Brief comparisons are made with some results found in the literature for planetary nebulae and for other novae.

The spectrum of Nova Lacertae, 1936, and its changes have been described by Harper¹ and by Edwards and Barber.² The visual light-curve (Fig. 1) is from material supplied by Mr. L. Campbell, of the Harvard College Observatory. Changes in luminosity and in the spectrum were interrupted by very few of the irregularities observed in most novae.

The present investigation consists of a study of the intensities of emission lines and of the continuous spectrum during the period from July 3 to November 21, 1936. In this interval the nova decreased in brightness from fifth to ninth magnitude. In the first part of July the spectrum was undergoing a rapid transition from the "post-maximum" stage to the "nebular" stage. By the end of July the nebular-type spectrum was well developed.

Spectrograms of the nova were obtained on forty-four nights from July 1 to November 21. All exposures were made with the two-prism quartz slitless spectrograph³ placed in the prime focus of the Crossley reflector of the Lick Observatory. This instrument gives spectrograms in excellent focus from $H\alpha$ to $\lambda 3600$. The definition becomes poorer at shorter wave lengths, although the spectrograms are still

¹ *Pub. Dom. Ap. Obs., Victoria*, **6**, 317, 1937.

² *M.N.*, **98**, 42, 1937.

³ W. H. Wright, *Lick Obs. Bull.*, **9**, 52, 1917.

usable at λ 3040. The emulsion used was Ilford Hypersensitive Panchromatic. The dispersion of the spectrograms is given.

Wave Length	Dispersion	Wave Length	Dispersion
6563 A.....	401 A/mm	4340 A.....	119 A/mm
5876.....	298	3969.....	89
5179.....	204	3130.....	38

On each night exposures were also taken of π^1 Cygni (magnitude 4.8, spectrum B₃k). Beginning October 14, BD +51°3341 (magnitude 7.1, spectrum B₂ek) was included on the observing program.

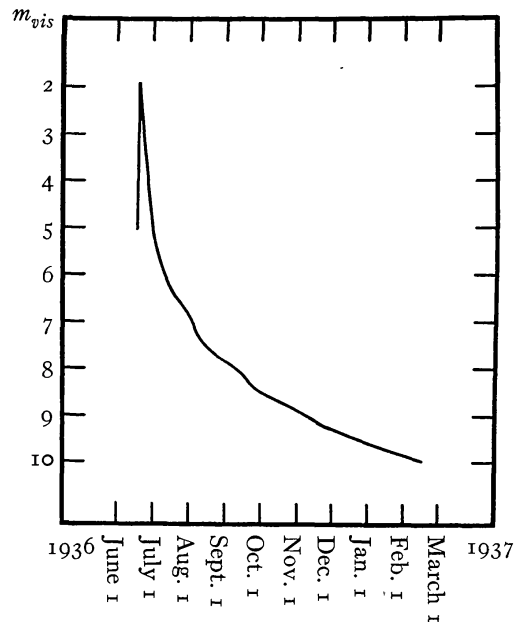


FIG. 1.—Visual light-curve of Nova Lacertae, 1936

These stars serve as spectrophotometric standards. All spectra were widened about 1/5 mm by trailing in right ascension. A coarse-wire grating, its dispersion crossed with that of the spectrograph, was placed over the telescope tube for most of the exposures. Two chief purposes are served by this arrangement: the usable range of intensity in a single exposure is increased, and images of sources of a known intensity ratio aid in the photometric calibration.

Spectrograms obtained on nine of the nights were chosen for reduction. The details of the observations are given in Table 1. The coarse-wire grating was used unless otherwise stated.

TABLE 1

m_{vis}	DATE (U.T.)	NOVA LACERTAE		STANDARD STAR		RE-MARKS†
		Exposure	sec z	Exposure	sec z	
5.4.....	1936 July 3.5	4 runs*	1.056	16 runs*	1.032	a
		16	1.055	32	1.032	
		32	1.054	70	1.032	
		80	1.053			
5.8.....	July 8.5	4 runs	1.052	16 runs	1.029	a
		16	1.052	32	1.029	
		32	1.052	60	1.030	
		80	1.058			
6.3.....	July 16.5	8 runs	1.076	16 runs	1.032	a
		32	1.064	32	1.031	
		64	1.056	64	1.030	
		128	1.053			
6.8.....	July 28.5	8 runs	1.098	16 runs	1.104	a
		32	1.094	34	1.106	
		64	1.085	64	1.124	
		128	1.071			
		40 min.	1.125			
7.1.....	Aug. 5.4	16 runs	1.057	16 runs	1.055	a
		64	1.071	32	1.057	
		128	1.063			
7.7.....	Aug. 26.3	4 min.	1.115	4 min.	1.119	a, e
		30	1.092	30	1.092	
		60	1.055			
8.1.....	Sept. 11.2	8.9 min.	1.029	3.4 min.	1.054	a
		50	1.052	45	1.036	
		59	1.170			
8.7.....	Oct. 15.2	45 min.	1.149	28 min.	1.058	b
		75	1.054			
9.2.....	Nov. 21.2	120 min.	1.460	35 min.	1.190	b
		129	1.066			

*"Runs" indicates number of times trailed with slow-motion motor.

† (a) Standard star for night was π^1 Cygni.

(b) Standard star for night was BD +51°3341.

(c) Grating was not used for nova exposure.

(d) π^1 Cygni exposed for third-order image.

(e) This is the only one of the nights on which transparency was poor. Differences in sec z are small.

(f) Nova exposure somewhat fogged by scattered moonlight.

REDUCTIONS

The data obtained directly from the observations are total intensities in the emission lines and intensity per angstrom in the background spectrum of the nova, both relative to the intensity in 1 \AA of the continuum of the standard star at the same wave lengths. With an assumption as to the energy distribution in the spectrum of the standard star, we can determine relative intensities in the nova spectrum; with one as to the non-variability of intensities in the spectrum of the standard star, we can obtain variations of nova intensities with time.

The characteristic curves of the photographic emulsion, used in the reduction of the spectrograms, were obtained on five excellent nights by means of stellar spectra calibrated with a series of diaphragms placed over the aperture of the telescope. The relation between density and the logarithm of intensity for the emulsion, at least in the low-density region used, was found to vary considerably with exposure time as well as with wave length. Mean curves were drawn for five wave-length regions and for six ranges in exposure time. The applicability of these mean curves to the spectrograms obtained on a given night was checked by means of spectra obtained with the coarse-wire grating. The logarithm of the intensity ratio of zero to first-order grating images, used in this check, was found to be 0.379 from spectra which were calibrated by means of the diaphragms. There were no significant variations of this quantity with wave length.

When the exposure times of nova spectrum and standard star spectrum differ (see Table 1), reciprocity-law failure must be applied in order to obtain relative intensities. A mean value of the Schwarzschild exponent was obtained from exposures made at the telescope. The use of a Schwarzschild exponent is, at best, an approximate procedure, but the ratios of exposure times were not large. In the cases of the larger ratios, it was usually possible to avoid direct use of the exponent by comparing intensities of several features measurable on two nova spectrograms taken during the same night.

It frequently happens that the exposure best suited for determining the intensity of an emission line is not strong enough to show the underlying background spectrum. In such a case the total apparent

intensity of the line is, in reality, the sum of the line intensity and the intensity of the background, integrated over the width of the line. This second term, which must be subtracted from the sum, is determined from stronger exposures made during the same night.

Corrections for differential atmospheric extinction were made in the usual way. The extinction factors were determined and, after correction for the air mass above Mount Hamilton, were found to agree satisfactorily with Fowle's values,⁴ in so far as variations with wave length are concerned. For wave lengths shorter than 3600 Å the observed values agreed well with an extrapolation of Fowle's data on a λ^{-4} relation, the corrections for ozone absorption having been included for the shortest wave lengths. The zenith extinction at λ 4500 is 0.31 mag., which may be compared with the value 0.32 mag. found by Fath⁵ with a photoelectric cell for a B3 star on a "good" night.

In the preceding paragraphs we have discussed the procedure involved in obtaining the fundamental observational quantities, namely, the intensities in the spectrum of the nova at various wave lengths relative to those in the spectrum of the standard star at the same wave lengths. The uncertainty of these quantities for the emission lines should be of the order of 0.1 in the logarithm, or about 25 per cent, though in favorable cases and for the continuum the second decimal possibly has significance. The greatest single cause of inaccuracy in the case of the emission lines probably lies in the difficulty of separating the lines on the microphotometer tracings from the background spectrum and from neighboring emission lines. The lines in the spectrum of Nova Lacertae were very broad.

In order to obtain relative intensities of features in the nova spectrum on any date, the intensity distribution in the continuous spectrum of the standard star must be known. No reliable determinations of intensity distribution in the spectra of stars are available; hence assumptions must be made. As a guide for our assumptions, the standard star, π^1 Cygni, was compared spectrophotometrically with ϵ Persei. The star ϵ Persei has been included on the observing programs of nearly all investigators of spectral-energy distribution,

⁴ *Smithsonian Physical Tables*, 1933.

⁵ *Lick Obs. Bull.*, 17, 121, 1934.

with varying results. The following parameters were adopted for the intensity distribution in the spectrum of ϵ Persei:

$\lambda\lambda$ 6600-3700..... Black body at 18,000° K
 $\lambda\lambda$ 3700-3100..... Black body at 25,000° K

As a result of the comparisons, I have assumed for π^1 Cygni

$\lambda\lambda$ 6600-3700..... Black body at 16,500° K
 $\lambda\lambda$ 3700-3100..... Black body at 20,000° K

$$D = 0.19$$

where D is the logarithmic decrease in intensity at the limit of the Balmer series. This quantity is to be considered more an observed than an assumed quantity. Changes of two or three thousand degrees in the temperatures used would not lead to significant corrections of the results.

The star π^1 Cygni was tested for variability by means of observations with photoelectric photometers at Mount Hamilton by Fath and by Kron, whose co-operation is gratefully acknowledged. The results obtained justify the use of π^1 Cygni as a standard of constant energy.

On the last two nights for which spectrograms were reduced, the fainter star, $+51^{\circ}3341$, was used as standard. Its spectral-energy distribution was found from numerous comparisons with π^1 Cygni. This choice of star was an unfortunate one, as it was found by Kron in the fall of 1937 to be variable over a range greater than 0.2 mag. The relative energies in the spectra of $+51^{\circ}3341$ and π^1 Cygni at the wave length effective for the photoelectric cell is assumed to be the mean of the values found by Kron on five nights. The evidence for or against variation in the spectral-energy distribution of the fainter star is inconclusive.

It is desirable to free the results of the observations from the effects of interstellar absorption as far as is possible. According to Greenstein,⁶ the λ^{-1} law of absorption is indicated by recent work. The results of Baade and Minkowski⁷ for regions in Orion and Perseus show serious departures from this law for longer wave lengths,

⁶ Greenstein, *Ap. J.*, **87**, 151, 1938; Stebbins, Huffer, and Whitford, *Ap. J.*, **90**, 209, 1939.

⁷ *Ap. J.*, **86**, 159, 1937.

but not for those in which we are interested, except possibly around $H\alpha$. The extension of this law to the short wave-length limit of our work, however, must be considered an extrapolation.

Greenstein reports that a small amount of dark nebulosity, extending from the north, covers the field of the nova, the logarithmic decrement, from star counts, being 0.15, with an uncertainty of less than 0.04. He also reports that star counts by J. W. Evans indicate a general photographic absorption in the southern Cepheus region, in which the nova is located, of 0.25 mag. per kiloparsec. Determinations at Mount Wilson⁸ and at Victoria⁹ from the intensities of interstellar lines set the distance of the nova at about 850 parsecs. Hence, we may take the general absorption as 0.08 in the logarithm, and the total photographic dimming as $0.08 + 0.15 = 0.23$, with an uncertainty of about 0.06. Then the correction to be applied to reduce the nova intensities, I , to transparent space is

$$\Delta \log I = +0.23 \frac{4400}{\lambda},$$

where 4400 Å is the photographic effective wave length as used by Greenstein. The writer is indebted to Dr. Greenstein for this information.

With a visual magnitude at maximum light of 1.9 mag., as reported by several observers, a distance of 850 parsecs, and a visual obscuration by absorbing material of 0.5 mag., the absolute visual magnitude of the nova at maximum appears to have been about -8.3.

The results of the reductions are given for the background spectrum in Figure 2 and for some of the emission lines in Table 2. In both cases the more uncertain values are indicated by parentheses. The unit of intensity is that contained in 1 Å of the continuum of π^1 Cygni at λ 5000. Uncertainties in the law of interstellar absorption, as well as in the assumed energy distribution of π^1 Cygni, affect directly the relative intensities for a given date but not their variations with time.

⁸ Merrill and Wilson, *Pub. A.S.P.*, **48**, 230, 1936.

⁹ Pearce, *Pub. A.S.P.*, **49**, 148, 1937.

Reductions were carried out for most of the emission lines which were comparatively unblended or for which the relative contributions of blending components could be obtained with fair accuracy. Exceptions are listed in the footnotes to Table 2. The points plotted for the background spectrum in Figure 2 are not necessarily in the continuous spectrum of the nova, though they were chosen as care-

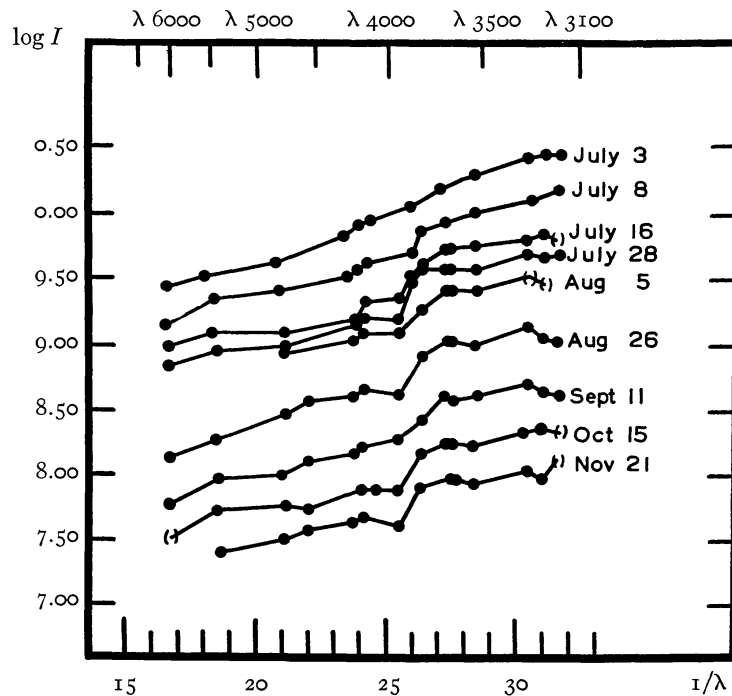


FIG. 2.—Logarithm of intensity per angstrom in the background spectrum of Nova Lacertae, corrected for interstellar absorption. Log intensity equals 0 for 1 Å of the continuum of π^1 Cygni at λ 5000.

fully as possible from that standpoint. Their choice for wave lengths greater than 3900 Å was guided by an examination of the slit spectrograms available at the Lick Observatory.

The results in Figure 2 and Table 2 may be reduced approximately to intensities received at the sun in ergs per square centimeter per second and less accurately to total energies emitted by the star in ergs per second, if we know the value of the unit of intensity. From the data given by Pettit and Nicholson¹⁰ for the total energies re-

¹⁰ *A. J.*, 58, 279, 1928.

TABLE 2
 LOGARITHMS OF TOTAL ENERGY IN EMISSION LINES
 CORRECTED FOR INTERSTELLAR ABSORPTION*
 (Unit: The Energy in 1 A of the Continuum of π^1 Cygni at λ 5000)

Line	July 3	July 8	July 16	July 28	Aug. 5	Aug. 26	Sept. 11	Oct. 15	Nov. 21
λ 6563 <i>Hα</i>	2.78	2.71	2.53	2.32	2.15	1.70	1.31	1.01	0.78
6300 [O I].....	0.87	0.92	(0.50)	(0.41)	(0.36)	(0.21)	(0.84)	9.36	9.34
5893 <i>Na</i> I.....	0.97	(0.64)	.....	.....	.....	.....	.....	.....	.....
5876 <i>He</i> I.....	.....	.....	1.18	0.94	0.77	0.32	0.02	9.40	9.18
5755 [N II].....	.....	1.28	1.24	0.97	0.89	0.86	0.70	0.56	0.30
5680 <i>N</i> II multi- plet.....	.....	0.73	0.91	0.87	0.61	0.32	(9.95)	(9.38)	(9.24)
5577 [O I].....	0.87	0.36	.....	.....	.....	.....	.....	.....	.....
5018 <i>Fe</i> II.....	1.52	1.07	.....	.....	.....	.....	.....	.....	.....
5007 [O III].....	.....	.....	1.48	1.67	1.59	1.52	1.48	1.41	1.26
4959.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4861 <i>Hβ</i>	1.97	2.02	1.70	1.59	1.39	1.02	0.73	0.36	0.01
4686 <i>He</i> II.....	.....	.....	(1.10)	(0.88)	(0.81)	(0.52)	(0.20)	(9.77)	(9.51)
4640 <i>N</i> III <i>et al.</i>	1.76	1.78	1.42	1.54	1.46	0.97	0.66	0.12	9.88
4363 [O III].....	.....	.....	(1.01)	(1.14)	1.14	1.13	1.09	0.68	0.30
4340 <i>Hγ</i>	1.68	1.69	1.41	1.29	1.19	(0.72)	(0.32)	(9.97)	(9.42)
4101 <i>Hδ</i> , <i>N</i> III.....	1.74	1.64	1.39	1.45	1.26	0.89	0.62	0.05	9.60
3970 <i>He</i> , [Ne III].....	1.40	1.29	1.01	0.88	0.80	0.43	0.09	9.72	9.45
3590 [Fe VII].....	.....	.....	.....	.....	.....	.....	.....	9.02	8.88
3432 [Ne V], O III.....	.....	.....	.....	1.03	0.88	0.82	0.47	0.10	9.85
3335 [Ne III], [Ne V], O III.....	.....	.....	.....	.....	.....	0.08	9.83	9.42	9.17
3270 O III.....	.....	.....	.....	.....	.....	9.95	9.62	9.12	.....
3203 <i>He</i> II.....	.....	.....	.....	0.78	.....	0.21	9.90	(9.17)	(8.84)
3125 O III.....	.....	.....	.....	1.30	.....	0.94	0.55	0.03	9.48

* Values in parentheses are considered somewhat less reliable than the remaining values.

Notes on blends:

- λ 6563 Undoubtedly blended with λ 6548 and λ 6584 of [N II], particularly on the later dates. Effects of blending unimportant. See p. 280.
- 6300 Seriously blended with λ 6364. That the latter line is not due to [O I] exclusively is indicated by the great variations in the relative intensities of the two lines. The probable contributor to λ 6364 is N II.
- 5876 + 5893 Probably *Na* I exclusively on July 3 and 8. *He* I much stronger by July 16. *Na* I absent by July 28.
- 5018 Probably contributes slightly to λ 5007 on July 16.
- 4640 The contributions due to the various elements undoubtedly vary considerably. The whole blend from about λ 4610 to λ 4660 is included.
- 4363 + 4340 The intensity of the sum is measured. The relative contributions of the two components from July 16 onward were calculated from measures of those parts of the separate lines visible, λ 4340 being the sole contributor before that date. Slit spectrograms were used for this purpose on July 16 and 28.
- 4101 This line includes the important *N* III pair at λ 4097 and λ 4103. No means of separating the elements directly from the observations is envisaged. *N* III probably becomes important beginning July 16 or 28.
- 3970 The remarks on the preceding line hold with respect to the *H* and [Ne III] contributions.

ceived outside the atmosphere from six B3 stars, the energy flux from a star of the visual magnitude of π^{τ} Cygni, 4.78 mag., and this spectral type should be 1.65×10^{-12} cal cm⁻² min⁻¹. Then, from the laws of Stefan and Planck for perfect radiators and a temperature of 16,500° we find the intensity in 1 Å at 5000 Å to be 7.8×10^{-11} erg cm⁻² sec⁻¹, which is the unit of intensity. Thus, 10.11 should presumably be subtracted from the values of Table 2 and of Figure 2 to reduce them to logarithms of intensities received at the sun if space were transparent. Using a distance of the nova of 850 parsecs, we find the quantity to be added to the values of Table 2 and of Figure 2 to obtain logarithms of energies emitted in ergs per second by the nova in the spectral features under consideration to be 30.9.

DISCUSSION

In this discussion the point of view is taken that the emission lines are produced in a rarefied envelope surrounding a central star or nucleus. It is further assumed that radiation from this nucleus is the agent exciting the atoms of the envelope to emission and also that it is the source of the observed continuous spectrum for wave lengths greater than 3700 Å.

I. THE CONTINUOUS SPECTRUM

The reduced intensities in the background spectrum are shown in Figure 2, plotted as logarithm of intensity $\equiv \log I$ against $1/\lambda$. It is not claimed that all of the plotted points lie on the true continuous spectrum of the star, and hence they are not suitable for a statistical treatment.

Beginning July 16, or possibly July 8, there is observed a pronounced strengthening of the spectrum on the violet side of λ 3700,¹¹ which is near the Balmer series limit. July 16 is, however, the first of the dates on which we could expect to detect this emission with certainty, even if it were present earlier. In the first place, on the earlier dates the ultraviolet spectrum is so dominated by metallic emissions and absorptions that the intensities measured are considered unreliable indications of the continuum. But by July 16 the metallic lines are weak; and from this date on, the ultraviolet points

¹¹ The continuous absorption in this region of the spectrum of π^{τ} Cygni has, of course, been taken into account in the reductions.

measured are more likely to be in the true continuum than any other series of points. In the second place, and probably more important, the strengthening is best indicated with respect to the point at 3930 Å. This point becomes available only after the disappearance, by July 16, of K emission and $H + H\epsilon$ absorption. If the continuum in this region could be observed on the earlier dates, it is possible that a strengthening at λ 3700 would be apparent.

The course of the continuous spectrum on the red side of λ 3700 is uncertain. In drawing its slope, the weights given the individual points shown in the plots depend on their behavior from night to night and on the appearance of the slit spectrograms. The point at λ 3930 was usually given high weight. No significant change in intensity distribution over the period of observation is indicated. This result is at a variance with that of Petrie.¹² The average slope, relative to that of π^r Cygni, leads to a color temperature of 1.43×10^4 degrees K, with values falling between 1.37 and 1.54×10^4 . Just what may be the physical significance of this quantity is not clear. Theories¹³ relating to the production of a spectrum of the nebular type indicate that much more radiation is required from the exciting source in the far ultraviolet region, beyond the head of the Lyman series of hydrogen, than is emitted by a black body at 14,000°. If we grant that the observed continuum redward of 3700 Å originates in the same exciting source, radical departures from black-body distribution are indicated. This has been pointed out by other observers of energy distribution in the spectra of novae.

If we could take the approximate constancy of the nova's color temperature as an indication of constancy of distribution of energy throughout the spectrum of the exciting star, changes in the radius of the star's photosphere could be computed directly from the fading of this spectrum. Such a computation, based on the decrease in intensity at λ 3930, yields a decrease in the radius by a factor of 7.5 between July 16 and November 21. Calculation of the actual values of the radius is dependent on the assumption of at least approximately black-body distribution of intensity, and hence it is felt that a statement of the results would be misleading.

¹² *Pub. Dom. Ap. Obs., Victoria*, 6, 338, 1937.

¹³ E.g., Zanstra, *Ap. J.*, 65, 63, 1927; Bowen, *Ap. J.*, 81, 1, 1935.

The intensity and course of the continuous spectrum in the ultraviolet region, which contains the continuous Balmer emission, is probably best shown by averaging the observed values of $\log I$ in two groups of three points each, centered at wave lengths 3600 Å and 3230 Å. The relative intensities $I_{3930} : I_{3600} : I_{3230}$ undergo very little change, the average and nearly constant values being

$$\log \frac{I_{3600}}{I_{3930}} = 0.38 \text{ and } \log \frac{I_{3230}}{I_{3930}} = 0.46 .$$

It is a curious fact that the value of $\log I_{3230}/I_{3600} = 0.08$ corresponds to a black-body temperature of 1.38×10^4 degrees, very near the color temperature found for the longer wave-length region. In fact, extrapolation of the continuum through $\lambda 3930$ to $\lambda 3600$ and $\lambda 3230$ shows $I_\lambda/C_\lambda = 2.0$ at both wave lengths, where C_λ is the extrapolated intensity; i.e., the ultraviolet continuum is twice as strong as that obtained by an extrapolation of the intensity distribution at longer wave lengths.

There is little doubt that the ultraviolet continuum consists of the sum of the radiations from the stellar nucleus and from continuous emission at the head of the Balmer series in the envelope. Given the distribution of intensity in one source, the distribution in the other can be deduced from the observations. As pointed out by Page,¹⁴ however, the stellar radiation may suffer considerable continuous absorption in the same region. The distribution of intensity in the continuous emission at the head of the Balmer series, if due to electron captures by hydrogen, as seems most likely, depends on the electron temperature. For any probable value of this parameter (see below), the intensity of the emission should decrease fairly rapidly with decreasing wave length. To account for the observed distribution, then, we must postulate that the stellar intensity rises considerably more rapidly through the ultraviolet region observed here than in the case of a black body at $14,000^\circ$.

2. THE EMISSION LINES

In order to show variations with time, the logarithms of the reduced intensities of the emission lines, E , are plotted in Figures 3

¹⁴ *M.N.*, 96, 604, 1937.

and 4, in which the abscissae are the logarithms of ($t^{\text{days}} - \text{June } 20$). June 20 was the date of maximum light. The first, Figure 3, shows the values of $\log E$; the second, Figure 4, the values of $\log E/C$, where C is a mean intensity of the continuous spectrum. All the prominent lines of the later stages of the nova's development in the wave-length region of observation are shown, with the exception of the very broad blends due to $He\ I$, H , and $[Ne\ III]$ near $\lambda\ 3880$ and to $[O\ II]$, H , and $O\ III$ near $\lambda\ 3750$. Plots for several of the weaker lines also are given.

Study of the plotted results leads to the following conclusions and inferences.

a) Metallic lines and $\lambda\ 5577$ of $[O\ I]$ disappear rapidly during the transition period of the first part of July, while the observable permitted lines of higher excitation strengthen. Evidently conditions become more favorable, during this transition period, for the production of lines of higher excitation and ionization energies. The fact that after July 16 or 28, however, differences in behavior due to differences in the stage of ionization are secondary, may be regarded as evidence that, after the transition period, departures from a steady state are not great. More specifically, the number of ionizations of an element in unit time does not differ greatly from the number of recombinations.

b) Permitted lines keep approximately constant intensities relative to the continuum from the latter part of July until September or later. Nova Lacertae is not typical among novae with respect to variations of E/C . Some novae show marked fluctuations of these ratios, which are closely correlated with fluctuations in light. The light-curve of Nova Lacertae shows almost no such irregularities.

The constancy of E/C with time is puzzling. Consider the case of hydrogen, for example. Let it be assumed that the predominant agency for Balmer emission lines is the recombination of hydrogen ions with electrons, and that the observed continuous spectrum, C , has its source, at least for the most part, in the radiation of the central star. It can then be shown by relatively simple arguments that E is not determined directly by C , and in particular that E should be expected to decrease more rapidly than C ; and that the observed constancy of their ratio implies either a fortuitous relation connecting the radiation of the star with conditions in the (expanding) nebu-

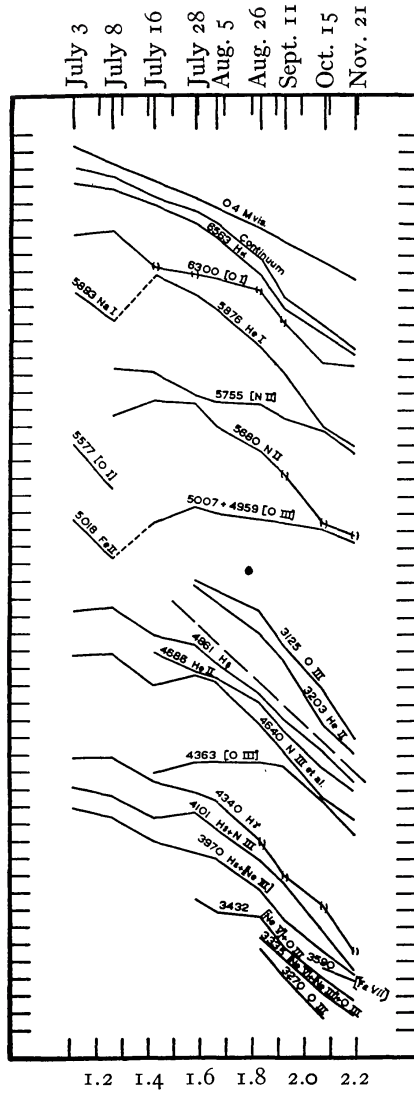


FIG. 3
log (t^d-June 20)

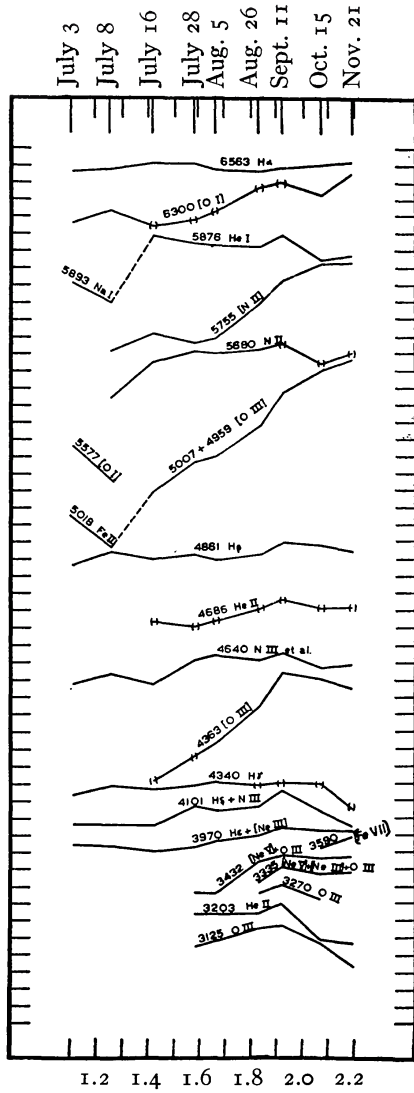


FIG. 4
log (t^d-June 20)

FIG. 3.—Logarithm of total intensities of emission lines. Scale of ordinates: one division equals 0.2 in log intensity. Zero points of ordinates of different curves are arbitrarily adjusted.

FIG. 4.—Logarithm of total intensities of emission lines relative to the continuous spectrum. Ordinates as in Fig. 3.

la or some causal relationship of an obscure nature. Neither of these alternatives is very satisfactory. It is conceivable that a continuous ejection of matter from the nucleus at the proper rate could be instrumental in maintaining the observed relations.

c) Forbidden lines rise rapidly with respect to the background till the first of September or later. Increases in absolute intensity of the forbidden lines are either very slight or unobservable.

Many of the emission lines show a pronounced rise on September 11 relative to the continuum, and it is seen from the absolute plots that this is a case of an unusually rapid drop in the continuum rather than of a slower decrease of the lines. A careful examination of the reductions leads the writer to believe that the effect is real.

Due caution must be exercised in attempting to draw conclusions concerning physical conditions in the expanding envelope from the behavior and relative intensities of the emission lines. Three difficulties may be mentioned. First, it is evident that conditions vary greatly in different parts of the envelope. For example, the [O I] nebular lines are fairly strong at the same time that the [O III] lines are very prominent. Second, changes in intensity may be caused by gain or loss of matter in the envelope. Third, it is not always a straightforward matter to predict what effect changes in physical conditions may have on the intensity of a line. The discussion by Menzel¹⁵ and by Bowen and Minkowski,¹⁶ for example, points out that it is possible to draw various conclusions concerning the effect of electron pressure on the intensity of a forbidden line by oversimplifying the physical picture in various ways.

Whatever conclusions are drawn from the intensities of the lines must refer to a set of conditions averaged over the regions of the envelope in which the lines under consideration are produced.

Hydrogen.—In the accompanying table are given the intensities relative to those of $H\beta$ of the hydrogen lines believed to be unblended, or, in the case of $H\gamma$, freed of serious blends. The values for $H\alpha$ are included, since in the discussion of [N II] below it is concluded that the intensities of the nebular pair at λ 6548 and λ 6584 are very small with respect to the intensity of $H\alpha$. Also shown in the table are the relative intensities predicted¹⁷ on the assumption

¹⁵ *Nature*, **142**, 644, 1938.

¹⁶ *Nature*, **142**, 1079, 1938.

¹⁷ Baker and Menzel, *Ap. J.*, **88**, 52, 1938.

that the upper levels are populated as a result of electron captures and subsequent downward transitions. The effects of population by absorption of Lyman line emission are also taken into account. These values are for an electron temperature of $10,000^\circ$ K. They are not very sensitive to changes in T_e . Values in the columns head-

LOGARITHMS OF RELATIVE INTENSITIES
IN THE BALMER SERIES

	$H\alpha$		$H\beta$	$H\gamma$		$H\delta$		$H\epsilon$	
	Lick	V		Lick	V	Lick	V	Lick	V
July 3.	0.81	0.21	0.00	9.71	9.44	9.77	9.50	blend	9.41
July 8. . . . .	.69	.....	.00	9.67	9.91	9.62	9.82	9.27	9.45
July 16. . . . .	.83	.....	.00	9.71	9.83	blend	9.83	9.31	9.52
July 28. . . . .	.73	.....	.00	9.70	9.86	blend	9.76	9.29	9.40
Aug. 5. . . . .	.76	.....	.00	9.80	9.96	blend	9.70	blend	9.31
Aug. 26. . . . .	.68	.....	.00	(9.70)	.....	blend	.....	blend	.....
Sept. 11. . . . .	.58	.....	.00	(9.59)	.....	blend	.....	blend	.....
Oct. 15. . . . .	.65	.....	.00	(9.61)	.....	blend	.....	blend	.....
Nov. 21. . . . .	.77	.....	.00	(9.41)	.....	blend	.....	blend	.....
Theoretical.	0.40	.....	0.00	9.71	.....	9.49	.....	9.31	.....

ed "V" are from McKellar's paper.¹⁸ In each case the Victoria spectrograms were exposed within one or two days of those at Lick.

No definite trends with time are shown by the Lick observations. All fluctuations, with the possible exceptions of the value for $H\alpha$ on September 11 and for $H\gamma$ on November 21, are within observational uncertainty. The observed relative intensities of $H\beta$, $H\gamma$, and $H\epsilon$ are in good agreement with those predicted. Against this agreement of observation and theory may be set the results for $H\alpha$ and $H\delta$. The large $H\alpha/H\beta$ ratio is in the direction found in various objects. Self-reversal has been advanced¹⁹ as an explanation of this phenomenon. The strength of $H\delta$ on the earliest dates is puzzling. Its behavior later on is compatible with the assumption that blending with N III radiations is involved.

The electron-capture theory²⁰ predicts the way in which the number of electron captures per second by protons is distributed among the different energy levels of the hydrogen atom as a function of the velocity distribution (or temperature) of the electrons. The theory

¹⁸ *Pub. Dom. Ap. Obs., Victoria*, **6**, 347, 1937.

¹⁹ E.g., Woolley, *M.N.*, **96**, 514, 1936. ²⁰ Cillié, *M.N.*, **92**, 820, 1932; **96**, 771, 1936.

yields, in addition to the method of the Balmer gradient, two methods of computing the electron temperature from observed intensities. The assumption is made that the velocity distribution is Maxwellian. In both of these methods the intensities involved are more sensitive to differences of electron temperature than is the Balmer gradient. The first of the methods uses the intensity of a Balmer line relative to the intensity per unit wave length of continuous emission at the head of the Balmer series. The second method is based upon the distribution of energy in the continuous emission.

For the first method, the intensity of $H\beta$ and of the continuous emission at λ 3600 is used; for the second, the slope of the emission in a region about 140 Å in extent centered at λ 3600, which is free from emission and absorption features from about July 12 till the middle of September. In the application of both methods, correction is made for the underlying stellar continuum by extrapolating a black-body distribution for 1.43×10^4 degrees through the continuum at λ 3930. Although the justification of this procedure is admittedly dubious, it is to be noted that the results obtained by the two methods are affected by it in entirely different manners. The values cannot be obtained for July 3, while those for July 8 are of very low weight. It should be mentioned again that the relative intensities of emission at λ 3600 and λ 3200 lead to nearly infinite electron temperatures. The values of the electron temperature found by the two methods are herewith listed.

$T_e \times 10^{-3}$

	Method 1*	Method 2†		Method 1*	Method 2†
July 8.....	(10.3)	(14.2)	Aug. 26.....	11.2	4.9
July 16.....	9.9	11.1	Sept. 11.....	19.0	4.7
July 28.....	11.2	10.6	Oct. 15.....	18.7	6.9
Aug. 5.....	9.8	8.6	Nov. 21.....	13.4	11.3

* Method 1: Ratio of $H\beta$ to Balmer continuum.

† Method 2: Slope of Balmer continuum at λ 3600.

The trend shown by the latter set of values is reversed in the former set. These reductions indicate that the electron temperature was around $11,000^\circ$ during the period of observation. Values that

may be more reliable are found in the discussion of [O III]. It is of interest to compare the foregoing results with those found from measures of the Balmer continuum in other objects.²¹ For the solar chromosphere at the 1932 eclipse Menzel and Cillié find $T_e \approx 10,000^\circ$, using Method 2. They find the same value from Method 1 if $H\gamma$, $H\delta$, etc., are used, but much higher values if $H\beta$ is used. Page's observations for two planetary nebulae give values near $T_e = 2000^\circ$ from Method 2 but give extremely high values from Method 1.

Forbidden lines.—Under the conditions prevailing in the “nebular” stage of a nova's development, electron collisions are considered²³ to be the agency principally responsible for the excitation of the low-lying metastable levels from which the forbidden lines arise. If changes in electron temperature are not large, then changes in the relative intensities of two forbidden lines of the same atom must be due to changes in electron pressure. The way in which pressure affects the relative intensities is well known.²² During the period over which the relative intensities of the nebular and auroral lines of an atom remain constant, it is tempting to conclude that the electron pressure is so high that electron collisions predominate over radiation in depopulating the metastable states, and their relative population depends only upon the electron temperature according to Boltzmann's formula.²³ As the pressure decreases, so that this is no longer the case, the intensity of the auroral line will decrease relative to that of the nebular lines of the same atom. For [O III] the relative intensities of nebular ($\lambda 4959$ and $\lambda 5007$) and auroral ($\lambda 4363$) lines remained about constant till around September 11. Assuming that Boltzmann's formula is applicable in this case, we can calculate the electron temperature in the relevant parts of the envelope. The required data are the observed relative intensities and the relative transition probabilities²⁴ of the lines. The results are:

$T_e \times 10^{-3}$			
July 16	8.3	Aug. 26	8.7
July 28	8.0	Sept. 11	8.6
Aug. 5	8.4		

²¹ Quoted by Cillié, *M.N.*, **96**, 771, 1936.

²² E.g., Menzel and Payne, *Proc. Nat. Acad. Sci.*, **19**, 641, 1933.

²³ K. Wurm, *Zs. f. Ap.*, **14**, 321, 1937. ²⁴ S. Pasternack, *Pub. A.S.P.*, **51**, 160, 1939.

If the procedure described is a valid one, the value of 8500° for the electron temperature is a more reliable one than the value of $11,000^\circ$ derived from hydrogen.

It is desirable to compute the combined intensity of the nebular pair of $[N\ II]$, $\lambda\ 6548$, and $\lambda\ 6584$, to determine its probable effect on the intensities of $H\alpha$. This can be readily accomplished by use of the intensity of $\lambda\ 5755$, the transition probabilities, and an electron temperature of 8500° , if a Boltzmann distribution of atoms is assumed for the metastable levels in this case also. The computed effect of the $[N\ II]$ lines is never more than 0.02 in the logarithm, so that our neglect of it appears to be justified.

Comparison with planetary nebulae.—Aside from obvious differences due to the expansion velocity, conditions in the envelope surrounding a nova in the later stages of its development are usually considered to become similar to those in the planetary nebulae. Dr. Swings points out that the chief differences in the appearances of the spectra of the two kinds of objects are due to the presence of lines of atoms of higher atomic weight in the case of the novae. It is of interest to compare some of the results of this study with intensities obtained for the planetary nebulae. The latter are taken from the papers of Plaskett,²⁵ Berman,²⁶ and Page.¹⁴ The accompanying table gives the largest and smallest values observed by them for the logarithms of various ratios. Intensities were chosen for a restricted wave-length region to minimize effects of reduction methods.

COMPARISON WITH PLANETARY-NEBULAE LOGARITHMS
OF RELATIVE INTENSITIES

	PLANETARY NEBULAE		NOVA LACERTAE
	Largest Measured	Smallest Measured	
1. $He\ II\ 4686/H\beta$	9.8	9.1	9.4; remains about constant
2. $[O\ III]\ 5007+4959/H\beta$. . .	1.3	0.7	0.1 to 1.2, increasing steadily
3. $[O\ III]\ 5007+4959/[O\ III]\ 4363$	2.3	1.7	0.4 till Sept. 11; increases to 1.0

²⁵ *Pub. Dom. Ap. Obs., Victoria*, 4, 187, 1928.

²⁶ *Lick Obs. Bull.*, 15, 86, 1930.

If we assume absorption of ultraviolet stellar radiation followed by recombinations to be responsible for the permitted lines, we may conclude from item 1 of the table that the distribution of energy emitted by the nuclear star of the nova in the far ultraviolet is not greatly different from that emitted by the nuclear star of an average planetary, provided the relative abundances of H and He are the same. The effect of the special resonance mechanism mentioned by Bowen¹³ for the excitation of λ 4686 should not alter the conclusion greatly. The strength of λ 3203 of He II relative to that of λ 4686 indicates that this mechanism is by no means the predominant one for the excitation of λ 4686 in the nova.

If the electron temperature of the nova were comparable with that in the planetary nebulae, we could readily conclude from item 3 of the table that, although the electron density in the nova was decreasing, by November 21 it had not yet become so low as in the planetary nebulae. If the low electron temperatures obtained for planetary nebulae by Page¹⁴ are correct, however, we cannot draw this conclusion. The same difficulty is encountered in a consideration of item 2 of the table above.

Comparison with other novae.—As indicated by its spectrum, Nova Herculis, 1934, has been in the nebular stage since June, 1935. Intensities for the period July–September, 1935, have been published by Oehler.²⁷ Some comparisons with Nova Lacertae follow:

COMPARISON WITH NOVA HERCULIS: LOGARITHMS
OF RELATIVE INTENSITIES

	NOVA HERCULIS		NOVA LACERTAE
	June–July	Aug.–Sept.	
4686/ $H\beta$	9.2	9.3	9.4
5007+4959/ $H\beta$	1.0	1.5	0.1–1.2, increasing
5007+4959/4363.....	0.7	1.1	0.4 till Sept. 11, increasing to 1.0

The comparisons require little comment. The results for the two novae are of the same order, and the trends are in the same direction. The value of $E_{5007+4959}/E_{4363}$ remained approximately constant in

²⁷ *Zs. f. Ap.*, 12, 281, 1936.

Nova Herculis from June 20, 1935, the first date listed by Oehler, to July 25, 1935. From his value, using the method discussed above, we derive an electron temperature for Nova Herculis of 7.5×10^3 degrees, slightly lower than the value found in the same manner for Nova Lacertae.

Sayer has published measures of the spectrum of RS Ophiuchi after its maximum in 1933.²⁸ Reductions were made for dates quite closely spaced, and the results show large fluctuations. The values listed below are means. The $H\alpha/H\beta$ ratio found by Sayer is markedly greater than the value for Nova Lacertae.

COMPARISON WITH RS OPHIUCHI: LOGARITHMS
OF RELATIVE INTENSITIES

	RS OPHIUCHI (1933)			NOVA LACERTAE
	Aug.	Sept.	Oct.	
$H\alpha/H\beta$	1.0	1.2	.....	0.7
4686/ $H\beta$	9.3	9.6	9.6	9.4
4363/ $H\beta$	8.8	9.2	Increasing from 9.3 to 0.3; constant after Sept. 11

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²⁸ *Harvard Ann.*, **105**, 21, 1937.