

SPECTRAL STAGES OF NOVAE

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ABSTRACT

Systems of absorption and emission lines in the spectrum of a typical nova are briefly enumerated and described. Criteria for assignment of a nova spectrum to stages of development are defined in terms of (1) emergence, maximum strength, and disappearance of each absorption system and (2) intensity ratios of certain pairs of emission bands.

Spectra of seven bright novae have been examined in detail. Dates and differences of magnitude from maximum light are tabulated for each of twenty-six spectral stages, and these are combined into a table of chronology of a typical nova spectrum. Some deviations of individual objects from the average and some differences between rapid and slow novae are discussed briefly.

INTRODUCTION

A few years ago the writer¹ published dates and magnitudes at which six bright novae passed certain stages of spectral development. That work was based mainly upon Ann Arbor spectrograms of five stars and upon what could be gleaned from the literature on Nova Pictoris. Since then, through the courtesy of the directors of several observatories, it has been the writer's privilege to examine a great number of additional spectrograms and to fill in the gaps which existed in the Ann Arbor series. In particular, a study of Lick and Yerkes plates of Nova Persei and of published reproductions of its spectrum has made it possible to add that star to the list of those which furnish a detailed record. In the course of this work it has also been possible to define several spectroscopic stages in addition to those which were listed in the earlier paper.

It is expected that a more detailed discussion of the typical nova spectrum will be published at a later date. In the following sections we give a brief summary of the absorption and emission systems and definitions of the spectroscopic stages.

ABSORPTION SYSTEMS

1. The *pre-maximum absorption* lasts from the earliest date at which any nova has been observed on the rise until at least a day or two after maximum light (longer in a few cases).

2. The *principal absorption spectrum* becomes dominant within the first few days after maximum. Its displacement is greater than that of the pre-maximum spectrum.² It usually resembles the spectrum of a class A or F supergiant.

3. The *diffuse enhanced absorption* is a set of very strong and diffuse lines of hydrogen and ionized metals, with a displacement roughly double that of the principal spectrum. Its lines tend to sharpen and become multiple in its later stages.

4. The *Orion absorption*, a set of strong diffuse lines of $He\ I$, $O\ II$, and $N\ II$ (sometimes with and sometimes without hydrogen), emerges later, with a velocity sometimes nearly equal to that of the diffuse enhanced spectrum but in some cases very different from the latter.

5. The strong absorption lines $N\ III\ 4097$, 4103 belong to the Orion spectrum, but they persist after the remainder of that system has disappeared.

The sequence of events will be evident from a study of the tables of dates of appearance and disappearance of these groups of lines (Tables 2, 3, and 4).

¹ *Ap. J.*, **85**, 362, 1937.

² The principal and pre-maximum absorptions coexist for a time shortly after maximum.

EMISSION SYSTEMS

1. In Nova Herculis an emission spectrum was associated with the pre-maximum absorption, and in some other novae there has been evidence of a faint *pre-maximum emission*.

2. The *principal emission spectrum* appears after maximum light and is clearly associated with the principal absorption. The redward edges of its bands have displacements roughly equal and opposite to those of the lines of the principal absorption.

3. A *diffuse enhanced emission* spectrum is associated with the corresponding absorption, but it is commonly seen only in the lines of hydrogen and the strongest lines of *Fe II*, and at H and K of *Ca II*. Its redward edges have displacements about equal and opposite to those of the diffuse enhanced absorption lines.

4. *Orion emission* is associated with the Orion absorption. The bands are for the most part very vague and wide, and their centers are undisplaced.³

5. The diffuse "4640" *emission* and that at *N III* 4097, 4103 are part of the Orion emission spectrum, but they persist after that group as a whole has disappeared. It is especially emphasized that these lines also have members in the principal emission spectrum after the diffuse bands have disappeared.

6. The "*nebular*" *emission* spectrum is simply a continuation of the principal emission spectrum under altered physical conditions. The velocities and band structures leave no doubt on this point. The body of gas which gives rise to this set of bands eventually appears as a visible nebula expanding about the nova.

7. After the expanding nebulosity has faded, a *post-nova stellar emission* spectrum is visible on the continuous spectrum of the nuclear star. Its bright lines are much narrower than were the bands which constituted the spectrum of the expanding shell.

CRITERIA OF SPECTROSCOPIC STAGES

The first emergence, maximum strength, and disappearance of each absorption and emission system should obviously furnish a recognizable stage of development. In practice it is not possible to use the pre-maximum spectrum in this manner, but one stage is marked by its change from class B to class A. The maximum strength of *N III* absorption is poorly defined and not usable. The greatest intensity of the principal absorption follows so closely after its emergence that it is not sufficiently independent. With these exceptions, however, the absorption spectra define a number of stages.

The emergence and disappearance of the principal, diffuse enhanced, and Orion emissions are so closely bound up with the absorptions that they contribute no additional information. However, the emergence and disappearance of the "4640" band (its diffuse member in the Orion spectrum) are two usable stages.

Other criteria depend on relative intensities of lines in the principal emission spectrum. Changing conditions of excitation and density are reflected in the alteration from a set of bright lines of hydrogen, *Fe II*, and a few other elements, to a typically nebular spectrum. The following stages appear very well marked in those novae for which the record is sufficiently detailed.

1. The "[O I] *flash*."—A quick passage of the [O I] emissions from less conspicuous to more conspicuous than neighboring lines of *Fe II* is fairly well defined. The criteria are approximately

$$\frac{[O\ I] 5577}{Fe\ II\ 5534} = 1.2 ; \quad \frac{[O\ I] 6300}{Fe\ II\ 6248} = 1.6 ; \quad \frac{[O\ I] 6363}{Fe\ II\ 6248} = 1.0 .$$

³ The term "Orion emission" is strictly limited to these *diffuse* bands. Well-defined bands of *He I*, *O II*, *N II*, etc., with the same widths and structures as those of hydrogen, are referred to the principal spectrum.

2. *The "[N II] flash."*—A rapid increase of [N II] 5755 relatively to the permitted line N II 5680 and to the auroral [O I] line occurs shortly after the [O I] flash. The criteria are approximately

$$\frac{[N \text{ II}] 5755}{N \text{ II } 5680} = 1.3 ; \quad \frac{[N \text{ II}] 5755}{[O \text{ I}] 5577} = 1.8 .$$

3. *The "helium flash."*—A rather quick replacement of the D emission lines of Na I by the D₃ line of He I is well marked. As the He I line increases, the Na I emission fades rapidly. The criterion is

$$\frac{He \text{ I } 5876}{Na \text{ I } 5890-5896} = 1.0 .$$

4. In the ordinary photographic region, shortly after the helium flash, the line C II 4267 becomes stronger than Fe II 4233, and almost simultaneously He I 4472 surpasses Fe II 4515. A recognizable stage is given by the criteria

$$\frac{C \text{ II } 4267}{Fe \text{ II } 4233} = 1.0 ; \quad \frac{He \text{ I } 4472}{Fe \text{ II } 4515} = 1.0 .$$

5. *Additional stages.*—These are determined by the intensities of the nebular lines of [O III] relative to the emissions of hydrogen and Fe II. Thus, each of the following criteria defines a point in the normal development:

$$\text{First trace of } [O \text{ III}] 5007 ; \quad \frac{[O \text{ III}] 5007}{Fe \text{ II } 4924} = 1.0 ;$$

$$\frac{[O \text{ III}] 4959}{Fe \text{ II } 4924} = 1.0 ; \quad \frac{[O \text{ III}] 4363}{H\gamma} = 1.0 ;$$

$$\frac{[O \text{ III}] 5007}{H\beta} = 1.0 ; \quad \frac{[O \text{ III}] 4959}{H\beta} = 1.0 ;$$

$$\frac{[O \text{ III}] 4959}{H\beta} = 1.5 ; \quad \frac{[O \text{ III}] 4959}{H\beta} = 2.0 .$$

6. *Departures from uniformity.*—In the further history of the spectrum there are large departures from uniformity. Although some novae have shown the ratio [O III] 4959/Hβ as great as 5 or even 10, others for which the record is clear do not show it exceeding 2. Indeed, Nova Pictoris never had [O III] lines as strong as those of hydrogen, and in its record the corresponding stages were nonexistent. The maximum relative strength and the disappearance of the [O III] emissions likewise occur at very different parts of the decline in different novae, though there is rough agreement for Nova Aquilae, Nova Persei, and Nova Cygni.

It is important that in every case the determination of a stage from the criteria should be based on interpolation from several observations rather than upon a single datum. Allowance must be made for oscillatory changes in the line ratios which accompany fluctuations of light.

SPECTROSCOPIC STAGES OF SEVEN BRIGHT NOVAE

Most of the stages which have been mentioned can be recognized in the spectra of the seven bright novae of this century. The writer has made a detailed examination of most of the available spectrograms of these stars, with the exception of pure duplications. Curves have been drawn for each line ratio, and the stages have been interpolated from them. For each stage two quantities may be tabulated: (1) the time interval from

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TABLE 1

NOVA	LIGHT MAXIMUM		DIFFERENCES BETWEEN TRUE AND SMOOTHED LIGHT-CURVES	
	Date	Magnitude	Early Decline	Transition
Lac 1936. . . .	June 20.4*	+2.1	0 ^m 0	+0 ^m 5
Aql 1918. . . .	June 10.0†	-1.1	0.0	+0.7 to -0.4
Per 1901. . . .	Feb. 23.5†	+0.2	0.0	+0.8 to -0.8
Cyg 1920. . . .	Aug. 24.0†	+2.0	0.0	+1.4
Gem 1912. . . .	Mar. 14.5†	+3.5	-1.0 to +0.5	+0.4 to -0.5
Her 1934. . . .	Dec. 22.5*	+1.4	-0.9 to +0.9	+7:(min.)
Pic 1925. . . .	June 8*	+1.2	-1.3 to +1.1	+0.5

* U.T.

† G.M.T. (old style).

TABLE 2

DIFFERENCE OF MAGNITUDE FROM LIGHT-MAXIMUM TO EACH SPECTROSCOPIC STAGE FOR SEVEN NOVAE

Spectroscopic Stage	Nova Lac	Nova Aql	Nova Per	Nova Cyg	Nova Gem	Nova Her	Nova Pic	Adjusted Mean Δm
Change from B to A (pre-maximum absorption)	0 ^m 6	>1 ^m 7	0 ^m 6	>0 ^m 6	>0 ^m 6	1 ^m 8	>1 ^m 1	1 ^m 5:
Maximum light	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emergence of principal absorption spectrum	0.2	1.0:	0.3	0.2	1.4	0.8	0.2	0.6
Emergence of diffuse enhanced absorption	0.8	1.3	0.6	1.4	1.6	1.3	1.8	1.2
Maximum of diffuse enhanced absorption	1.6	1.7	2.0:	2.5	2.1	1.6	2.2	2.0
Emergence of Orion absorption	1.3	1.9	.....	2.2	1.7	2.3	3.0	2.1
[O I] flash	3.2	3.4	2.0:	2.7	2.1	1.6	.....	2.6
Multiple hydrogen absorption	1.9	2.3	3.6	3.5	2.4	3.0	2.3	2.7
Appearance of <i>N</i> III absorption	3.2	2.5	2.0	3.1	2.3	.....	3.4	2.7:
Maximum of Orion absorption	2.1	2.9	2.3:	2.7	2.4	3.1	3.3	2.7
Disappearance of diffuse enhanced absorption	2.5	2.9	3.0	4.1	2.6	3.1	3.1	3.0
Appearance of diffuse "4640" emission	3.2	3.4	3.5	3.2	2.2	2.4	3.3	3.0
[<i>N</i> II] flash	3.4	3.7	4.3:	4.3	2.5	2.2	[3.5]	3.3
Disappearance of Orion absorption	3.5	3.6	.....	3.5	2.6	3.2	3.5	3.3
Helium flash	4.0	4.0	3.6	4.3	2.6	[3.4]	.....	3.6
[O III] emission first traced	4.0	3.7	4.3:	4.5	2.7	[3.5]	3.4	3.7
λ 4267 = λ 4233; λ 4472 = λ 4515 (principal emission)	4.0	4.2	.....	4.8	2.7	[3.5]	3.4	3.8
λ 5007 = λ 4924	4.2	4.1	.....	5.1	2.7	3.6	3.8	3.9
Disappearance of principal absorption	3.9	5.0	4.1	4.8	3.2	3.2:	3.7	4.1
λ 4959 = λ 4924	4.3	5.0	4.3	5.6	3.5	[3.9]	3.9	4.4
Disappearance of <i>N</i> III absorption	4.1	5.0	.....	4.8	.....	.....	3.6	4.4:
Disappearance of diffuse "4640" emission	4.6	5.6	4.8:	5.4	5.5	3.2	3.8	4.7
λ 4363 = <i>H</i> γ	5.3	5.1	5.1	6.2	[3.9]	[4.0]	never	4.9
λ 5007 = <i>H</i> β	5.6	6.0	5.9	6.4	4.4	[4.3]	never	5.4
λ 4959 = <i>H</i> β	6.1	6.5	6.2	7.0	4.7	4.6	.....	5.8
λ 4959/ <i>H</i> β = 1.5	6.5	[7.0]	[6.8]	7.5	5.4	5.5	.....	6.4
λ 4959/ <i>H</i> β = 2.0	6.8	7.3	[7.1]	7.7	[5.7]	5.6	.....	6.7
λ 4959/ <i>H</i> β = 5	8.8	8.1	never	8.5	never	.....	.....	(8.5:)
[O III] maximum intensity . . . . .	.....	9.6	10.8	8.9	6.3	.....	.....	(9.5:)
Disappearance of [O III] . . . . .	.....	11.3:	11.1:	13:	8.3:	.....	.....	(11:)

maximum of light to the stage concerned and (2) the difference between the magnitudes at maximum and at the stage in question. In what follows we shall refer to these as Δt and Δm , respectively.

The determination of Δt would require no comment, were it not for the oscillatory changes of spectrum which accompany fluctuations of light. Where line ratios are concerned, smoothing of the curves has been resorted to as the only possible expedient. A joint study of the light and spectral variations has been made in each individual case.

The measurement of Δm also is rendered difficult by the irregular variations of light. Smoothed light-curves have been adopted for this purpose. Points which departed far from the smoothed curves were regarded as abnormal, and the spectrum was likewise considered abnormal at such times. By interpolation, however, it is believed that correlated smoothed spectral stages and smoothed magnitudes have been obtained. The adopted form of curve was one with continuous upward concavity, so drawn as to average the secondary fluctuations. In the transition stages, however, large deviations occurred in the direction of relative faintness of the true magnitude. Nova Herculis furnishes the most conspicuous example of such departure.

Table 1 gives dates and magnitudes of maxima and minima of the seven novae and shows the amount of deviation of the true light-curve from the smoothed one for two divisions of the decline—the “early decline” and the “transition.”⁴

In Table 2 the first column contains the designation of each spectroscopic stage, and the next seven give the values of Δm for each of the seven novae. The figures in brackets are “hypothetical” values, which depend on the use of the normal sequence of stages as a function of Δm for interpolating the positions of unobserved stages between well-observed ones. In the formation of the bracketed values, at least two stages preceding and two following the stage were used wherever possible. A couple of short-range extrapolations have been made, but no *fictional* stages have been introduced; for example, the last few stages which involve strong nebular lines were never reached by Nova Pictoris and hence the corresponding spaces in the table are blank.

The last column of Table 2 contains the “adjusted mean” value of Δm for each stage, based on all seven novae. In its formation the bracketed values have been included with full weight. In only one case does this differ from the mean of the observed values (bracketed figures omitted) by more than $0^m.2$.

The last three lines of the table, which are set apart from the rest, give data for the discordant late stages of the spectrum. They are included for completeness of the record and have not been used in any way which would influence the other results.

Table 3 gives in similar form the values of Δt in days after maximum light for all the stages of the seven novae. The figures in brackets are the intervals corresponding to the bracketed values of Δm in Table 2. At the foot of each column is given the time required to decline through 3.0 mag. from maximum, as measured on the smoothed light-curve. This interval is adopted as a unit for the time scale of each nova.

The last column of Table 3 contains the “mean relative Δt ” based on all seven novae. It is the logarithmic mean of the seven values of Δt when expressed in terms of the unit just defined, the time required to decline through 3.0 mag.

CHRONOLOGY OF A TYPICAL NOVA

When the logarithm of “mean relative Δt ” from Table 3 is plotted against the mean Δm from Table 2, all the points after light-maximum, with the exception of the first two, lie very close to a straight line. This line was used to form smoothed values of Δt , simply by reading off the logarithm corresponding to the mean Δm . Table 4 is the resulting chronology of a typical nova. The spectroscopic stage is named in the first column, Δm is given in the second, and the smoothed relative Δt (in units of the interval for a

⁴ These terms are defined in the writer’s study of light-curves of novae (*Pop. Astr.*, 47, 418, 1939).

TABLE 3
TIME INTERVAL IN DAYS FROM LIGHT-MAXIMUM TO EACH SPECTROSCOPIC STAGE FOR SEVEN NOVAE

Spectroscopic Stage	Nova Lac	Nova Aql	Nova Per	Nova Cyg	Nova Gem	Nova Her	Nova Pic	Mean Relative Δt
Change from B to A.....	1.0	-(> 1.02)	0.9	-(> 1.03)	-(> 1.05)	8.5	-(> 1.04)	0.1
Maximum light.....	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Emergence of principal absorption.....	0.4	0.2	0.7	1.0	3.5	2.5	+	0.04
Emergence of diffuse enhanced absorption.....	1.4	0.5	1.5	4.5	4.5	13.5	+	0.16
Maximum of diffuse enhanced absorption.....	3.3	2.0	7.0	10.5	10	32	+	0.42
Emergence of Orion absorption.....	2.6	2.6	.....	8	6.5	70	+	0.46
[O I] flash.....	10.0	10	7.0	13	10.5	31	.....	0.7
Multiple hydrogen absorption.....	4.0	4.6	20	21	16	93	.....	0.8
Appearance of N III absorption.....	10.6	5.0	7.0	16	15	.....	.....	0.8
Maximum of Orion absorption.....	4.8	6.0	9.0	13	16	96	.....	0.8
Disappearance of diffuse enhanced absorption.....	6.3	6.0	13	28	22	96	.....	1.0
Appearance of diffuse "4640" emission.....	10.0	9.0	18	17	11.5	77	.....	1.0
[N II] flash.....	13.0	12	36	32	19	64	.....	1.35
Disappearance of Orion absorption.....	15.0	11	.....	21	22	103	.....	1.25
Helium flash.....	20.0	14	20.0	32	22	.....	.....	1.5
[O III] emission first traced.....	20.0	12	33	35	23	.....	.....	1.6
λ 4267 = λ 4233; λ 4472 = λ 4515.....	20.0	16	.....	40	23	.....	.....	1.6
λ 5007 = λ 4924.....	25.0	15	.....	45	23	.....	.....	1.7
Disappearance of principal absorption.....	18.0	38	30	41	39	103	.....	2.0
Disappearance of N III absorption.....	23.0	37	36.0	57	51	.....	.....	2.6
Disappearance of diffuse "4640" emission.....	42.0	38	.....	40	.....	.....	.....	2.8
λ 4363 = $H\gamma$	51.0	68	54.0	50	271	103	.....	3.7
λ 5007 = $H\beta$	59.0	40	67	80	65	.....	.....	3.7
λ 4959 = $H\beta$	92.0	92	128	89	200	.....	never	6.2
λ 4959/ $H\beta$ = 1.5.....	107.0	163	189	161	307	197	.....	9
λ 4959/ $H\beta$ = 2.0.....	134.0	[230]	[300]	250	408	324	.....	14
		263	[330]	342	.....	410	.....	17
λ 4959/ $H\beta$ = 5.....	420	450	never	750	never	.....	.....	+( 50:)*
[O III] maximum intensity.....	.....	750	900	1000	540	.....	.....	+( 70:)*
Disappearance of [O III] emission.....	.....	2000	1600	5300	1050	.....	.....	+( 200:)*
3.0 mag. below maximum.....	8.5	7.0	13	15	35	93	150	1.00

* The last three values of "mean relative Δt " are merely intended to indicate the order of magnitude of the time interval. Individual novae differ widely in these last stages.

3.0-mag. decline) in the third. Considering the very large amount of observational material that has been incorporated in this study, it seems unlikely that any appreciable revision of this table will be possible until additional data are supplied by *future novae*.

Table 4 gives not only the spectroscopic history but the typical light-curve as well. A plot of Δm against Δt gives a smooth curve which may be regarded as the typical form for a nonfluctuating nova. The individual characteristics of the seven light-curves have been averaged out.⁵

TABLE 4
CHRONOLOGY OF A TYPICAL NOVA

Spectroscopic Stage	Mean Δm	Smoothed Relative Δt
	0	
Change from B to A (pre-maximum absorption)	(1 ^m 5)	(- 0.1)
Maximum light	0.0	0.0
Emergence of principal absorption spectrum	0.6	+ 0.04
Emergence of diffuse enhanced absorption	1.2	+ 0.16
Maximum of diffuse enhanced absorption	2.0	+ 0.42
Emergence of Orion absorption	2.1	+ 0.46
[O I] flash	2.6	+ 0.7
Multiple hydrogen absorption	2.7	+ 0.8
Appearance of N III absorption	2.7:	+ 0.8
Maximum of Orion absorption	2.7	+ 0.8
Disappearance of diffuse enhanced absorption	3.0	+ 1.0
Appearance of diffuse "4640" emission	3.0	+ 1.0
[N II] flash	3.3	+ 1.25
Disappearance of Orion absorption	3.3	+ 1.25
Helium flash	3.6	+ 1.5
[O III] first traced	3.7	+ 1.6
λ 4267 = λ 4233; λ 4472 = λ 4515	3.8	+ 1.7
λ 5007 = λ 4924	3.9	+ 1.9
Disappearance of principal absorption	4.1	+ 2.2
λ 4959 = λ 4924	4.4	+ 2.7
Disappearance of N III absorption	4.4:	+ 2.7
Disappearance of diffuse "4640" emission	4.7	+ 3.5
λ 4363 = $H\gamma$	4.9	+ 4.2
λ 5007 = $H\beta$	5.4	+ 6.2
λ 4959 = $H\beta$	5.8	+ 9
λ 4959/ $H\beta$ = 1.5	6.4	+ 14
λ 4959/ $H\beta$ = 2.0	6.7	+ 17
λ 4959/ $H\beta$ = 5	(8.5:)*	+(50:)*
[O III] maximum intensity	(9.5:)*	+ 70:)*
Disappearance of [O III] emission	(11:)*	+(200:)*

* The last three entries are merely intended to give a rough indication of the difference of magnitude and the time interval from maximum for these stages. Individual novae are extremely discordant in these final stages.

DISCUSSION

Inspection of Tables 2 and 3 will show that no individual nova conforms precisely to the average pattern. We therefore investigate briefly the deviations of individuals from the average. In Figure 1 the data are plotted for the four most rapid of the seven stars: Nova Lacertae, Nova Aquilae, Nova Persei, and Nova Cygni. The four plots in the upper half of the figure have the mean $\log \Delta t$ as abscissa and $\log \Delta t$ of the individual nova

⁵ In an earlier tabulation (McLaughlin, *op. cit.*, p. 367) the values of Δt were expressed in days, corresponding to Δm on the light-curve of Nova Lacertae 1936. The present tabulation is free from the objection of dependence upon the light-curve of a single object.

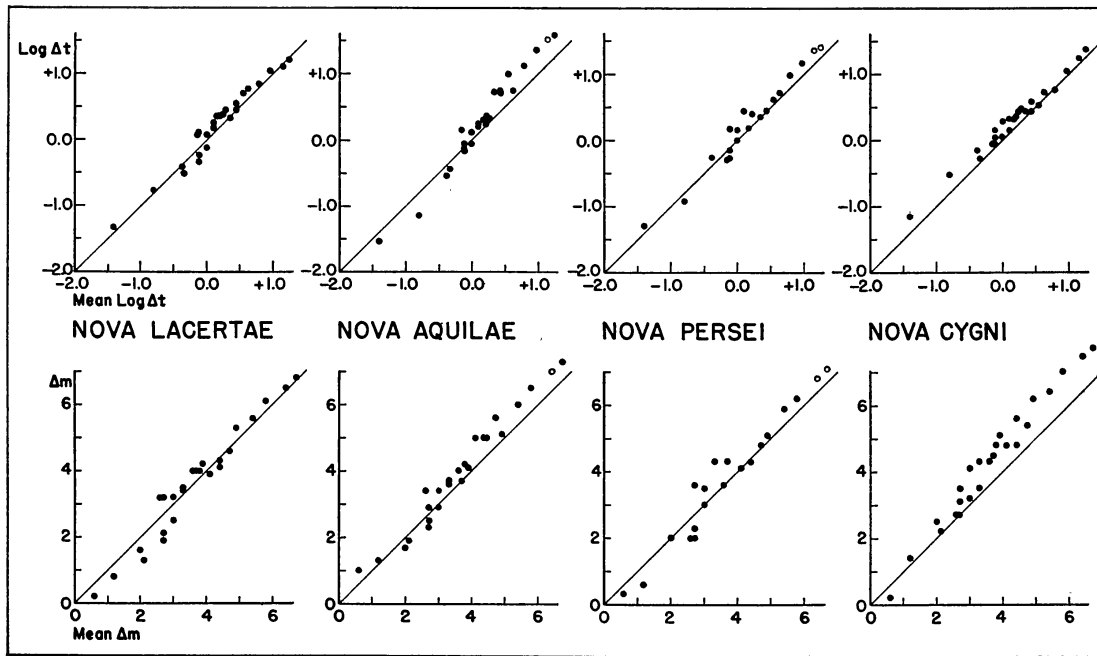


FIG. 1.—Individual comparisons of four rapid novae with the average spectroscopic behavior of seven novae. *Upper row*: Logarithms of relative time intervals from maximum to each spectral stage (unit is time required to decline 3.0 mag. from maximum). *Lower row*: Differences of magnitude from maximum at each stage. In each plot, the abscissa refers to the mean of seven novae; the ordinate refers to the individual object.

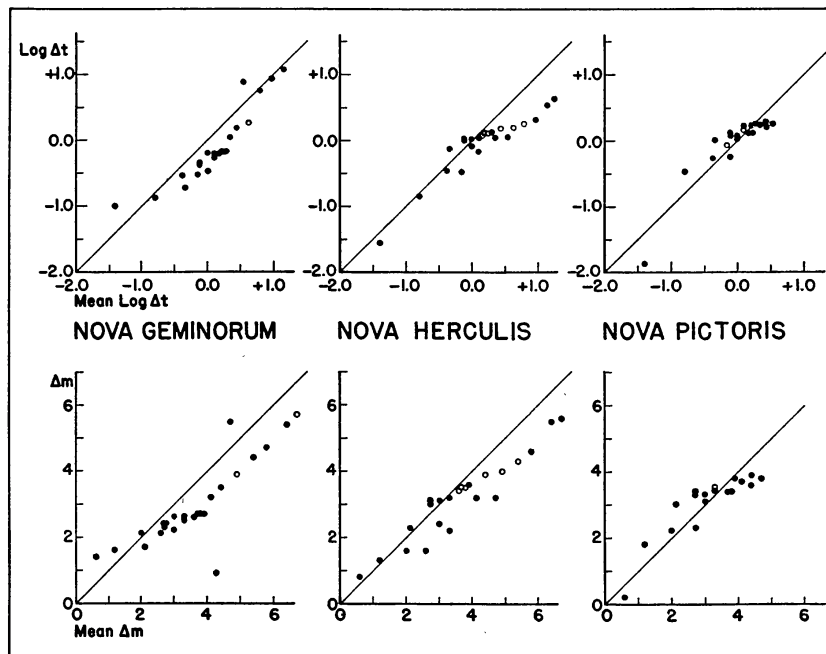


FIG. 2.—Individual comparisons of Nova Geminorum and two slow novae with the average spectroscopic behavior of seven objects. Arrangement of plots is similar to that of Fig. 1.

as ordinate. The four lower diagrams show the relations of Δm in the same form. Figure 2 is arranged in the same way for the other three novae, which declined more slowly.

Although some of the deviations are conspicuous, they are mainly systematic, and actual scatter is not great. The largest systematic differences in Δm are just $1^m.0$ in opposite directions for Nova Cygni and Nova Geminorum. The former would have departed even farther if the observed light-curve, instead of a smoothed one, had been used:

The departures of $\log \Delta t$ for the most part exhibit the same general form as those of Δm . Nova Cygni is an exception; in spite of the large deviation of Δm for the later stages, the values of $\log \Delta t$ lie almost on the 45° line. This is true also of Nova Geminorum. The differences in $\log \Delta t$ show that Nova Aquilae took 2.5 times as long to reach the later stages as one might have expected from the rapidity of its decline through the first 3 mag., while Nova Herculis took only one-fourth as long as expected. These are extreme cases; in general the accordance is much closer.

Another relation that can be seen in these diagrams is the relative rapidity of development in the later stages of the two slowly changing stars, Nova Herculis and Nova Pictoris. Both reached their later stages at a brighter magnitude than the average, and Nova Geminorum showed similar behavior. Likewise, the spectra of the two slow novae changed more rapidly in their later stages, as compared with their earlier ones.⁶

Finally, we mention another marked difference between rapid and slow novae. The two slow ones had strong forbidden lines of $Fe\ II$ in the "transition" stage. These have never been found in rapid novae. The $[Fe\ II]$ emissions also appeared in great strength in the slowly changing star DO Aquilae, in the still slower RT Serpentis, and in the very slow nova-like object η Carinae, in whose spectrum they are still strong. Apparently they are typical of the spectra of slow novae but are somehow inhibited by the physical conditions in the rapidly changing objects. On the other hand, a common feature of the spectra of rapid novae is poorly developed in the slow ones. The well-known absorption lines $N\ III\ 4097, 4103$ were not recorded at all in Nova Herculis and were very weak in Nova Pictoris. They were occasionally present in Nova Geminorum, but they had no continuous existence in great strength.

From the foregoing remarks it will be evident that Nova Geminorum had some of the characteristics of a slow nova, although its rate of decline was within the range of the rapid ones. Another point of difference between Nova Geminorum and other fast novae was the irregular nature of its early decline, which is strongly suggestive of the secondary maxima of Nova Pictoris.

The author is greatly indebted to the directors of several observatories for placing spectrograms at his disposal. Dr. Walter S. Adams, director of the Mount Wilson Observatory, and Dr. W. H. Wright, director of the Lick Observatory, made available a large number of spectrograms of many novae, both bright and faint. Dr. Otto Struve, director of the Yerkes Observatory, kindly loaned series of spectrograms of Nova Geminorum and Nova Persei. Other excellent series of Nova Geminorum were loaned by Dr. V. M. Slipher, director of the Lowell Observatory, and by the late Dr. F. C. Jordan, director of the Allegheny Observatory. To all of these the writer records his sincere thanks. The investigation was materially aided by a grant from the research funds of the Horace H. Rackham School of Graduate Studies of the University of Michigan, which is gratefully acknowledged.

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⁶ In this respect Nova Geminorum appears to differ from the two slow novae, but this may arise from the fact that the later criteria depend on $[O\ III]$, which was weaker in Nova Geminorum than in Nova Herculis. It was still weaker in Nova Pictoris, so that no corresponding points appear in Fig. 2.