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The Spectrum of Nova Geminorum

BY

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THE SPECTRUM OF NOVA GEMINORUM*

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The new star in the constellation Gemini, R.A. 6h. 49m. Dec. + 32° 13′ about 2° south of θ Geminorum, which was discovered by Enebo in Dombass, Norway, on March 12, 1912, was announced by telegraph from Harvard Observatory on March 13. There was some mistake and delay in the first message, so that no spectra were obtained at Ottawa until March 18. It is unfortunate, owing to the marked changes that have occurred in the spectrum since discovery, that some earlier plates were not secured, but those since obtained show very considerable changes in the nature of the emission and absorption bands which it is the purpose of this publication to describe.

Only seven spectra of the Nova have been photographed here, three on March 18, and one each on March 22, 25, 27, 29. These were all obtained with the single-prism spectrograph of the Dominion Observatory, the one regularly employed in radial velocity work, which gives a linear dispersion of 33.5Å per millimetre at H_γ. The observing data are given in the following table.

DATA OF OBSERVATION

Plate Number	G. M. Date	Hour Angle at End	Duration of Exposure	Remarks
	1912	h. m.	m.	
4892	March 18.56	2 11W	110	Partly cloudy and hazy.
4893	" 18.63	3 20	59	Seeing improved.
4894	" 18.67	3 40	15	Seeing improved.
4906	" 22.53	1 54	113	Seeing fair.
4914	" 25.54	2 20	120	Seeing fair.
4922	" 27.56	4 05	150	Cloudy and poor.
4923	" 29.56	3 05	125	Windy.

* The issuing of this paper has been long delayed after its writing on account of the change in the method of publishing the work of the Observatory.

A comparison of these plates shows that, although all are of the typical Nova form, considerable changes have taken place in the character of the spectra obtained, which can be divided into three distinct types.

The first of these includes plates 4892-3-4 made on March 18. These spectra show emission bands of hydrogen, helium and calcium, as well as a number of fainter bands whose origin is uncertain. The strongest of these bands, those of the β, γ and δ lines of hydrogen, show double maxima of intensity at the red side of the band, and, while this double maximum is not shown on the others, all the bands seem stronger on the same side. The absorption lines or bands usually accompanying the emission in the spectra of Novae are, however, very faint and diffuse, barely recognisable, let alone accurately measurable on the plates. The continuous spectrum is relatively strong, and the contrast between it and the gradually shaded edges of the emission bands is not sharply marked, rendering it difficult to certainly determine the boundaries of the latter. A number of more or less sharp metallic absorption lines are also present, the H and K of calcium being especially well marked, while the magnesium λ4481, some three or four of iron, and others of unknown origin are in decreasing order of distinctness.

The second of the types is followed in plates 4904 and 4916 obtained on March 22 and 25. In these the contrasts between continuous, emission, and absorption spectra are much more sharply defined and although the continuous spectrum is about equal in relative intensity to that in the first type, the presence of strong absorption lines renders the measurement more certain and accurate. The characteristic feature of these plates is the strong, moderately broad, and sharply defined pair of absorption lines at the *violet* side of most of the emission bands which shade off gradually on the red side. So pronounced and generally prevalent are these lines that a faint pair served to prove the presence of the helium λ4472, which was not accompanied by any visible emission. The narrow absorption lines H and K and two or three of iron are still present.

The principal change occurring in the third type, present in plates 4922-3 on March 27 and 29, is the increasing contrast between continuous and emission spectrum. The former has become relatively weak and possibly for this reason the second one of the pair of absorption lines of the previous type has disappeared. The emission bands now consist of a strong, sharply defined central portion some 25Å wide with weak shaded portions on each side, separated, at least on the violet side, from the central band by absorption. Owing to weaker continuous spectrum and probably insufficient exposure the calcium H and the magnesium λ4481 are the only sharp absorption lines present and these are not so accurately measurable as formerly.

A very good idea of the character of all these spectra can be obtained from their reproductions, assisted by the intensity curves drawn from approximate visual estimates on the figure, but a definite idea of the positions of the bands and lines and the relations in the successive types can best be obtained from the measures, which are herewith tabulated.

MEASURES

4892–3	4906	4914	4922	4923	Means	Remarks
5035.0	5035.9	5038.9	5036.4	5036.5	5036.5	Beg. Em., Abs.
5017.3						Abs. Bd. (ft.)
			5007.2	5009.2	5008.2	Min.
5003.7	5003.2	5005.2			5004.0	End Em., Abs. Line.
	4993.2	4994.8			4994.0	Brd. Abs.
			4974.4	4982.5	4978.4	Indef. End Em.
4996.4						Beg. Ft. Bd.
4956.7						End Ft. Bd.
4940.2	4941.3	4943.4	4939.0	4938.9	4940.6	Def. Beg. Em., Abs. Line.
4912.8	4910.4	4911.3	4913.2	4911.5	4911.8	Def. End Em., Abs. Line.
	4900.9	4900.5			4900.7	Brd. Abs.
4883.6		4887.5	4889.0	4890.2	4887.5	Def. Beg. Em., Abs. Line?
	4878.2		4877.3	4878.0	4877.6	Def. Increase Em.
4874.4 4871.3			4872.8	4872.3	4872.7	Max. Em.
4863.9			4864.9	4863.6	4864.2	Indef. Min., Abs. Line.
4860.9						Abs. Line.
4842.5	4847.2	4847.9	4849.0	4847.5	4847.9	Def. End Em., Abs. Line.
	4836.8	4838.4			4837.6	Abs. Line.
			4835.9	4836.2	4836.0	End. Ft. Em., Abs. Line?
4750.6						Ft. Abs. Bd.
4684.8				4682.7	4683.7	Indef. Increase, Beg. Bd.
				4671.1		Increase in Em.
4640.1						Max. Em.
4633.8						Ft. Abs. Bd.
4628.5				4628.5	4628.5	Max. Em.
4611.2	4611.4	4608.6	4606.6		4609.5	End Em., Abs. Line.
	4600.6	4598.5			4599.5	Abs. Line (ft.)

MEASURES—*continued*

4892–3	4906	4914	4922	4923	Means	Remarks
4596.5			4596.7	4597.1	4596.8	Beg. Em.
4594.8						Strong Max.
4589.3			4588.7	4587.2	4588.4	Indef. Abs.
4570.7	4568.1?	4572.3	4571.7	4571.1	4571.5	Abs. Line.
		4562.0			4562.0	Abs. Line.
				4564.3		Beg. Em.
4560.1			4560.0	4560.3	4560.1	Max.
4556.1						Abs. Line.
4545.2	4548.3				4546.7	Abs. Line.
4538.1	4537.3		4540.3	4538.1	4538.4	End Em., Abs. Line.
4528.2	4528.1				4528.2	Abs. Line.
			4536.2	4534.7	4535.4	Beg. Em. Bd.
4522.7						Abs. Bd.
	4510.7					Abs. Line?
4504.8	4503.9		4507.5	4508.0	4506.0	End Em., Abs. Line.
4496.2						Abs. Bd.
4481.7			4481.1	4481.0	4481.3	Abs. Line (Mg. 4481).
		4459.5			4459.5	Abs. Line.
	4451.0	4449.6			4450.3	Abs. Line.
	4405.3					Ft. Abs. Line (Fe. 4405).
4392.9						Ft. Abs. Line (Fe. 4405).
4389.7						Ft. Abs. Line (Fe. 4405).
	4383.5					Ft. Abs. Line (Fe. 4383).
4372.8						Ft. Abs. Line (Fe. 4383).
4371.0			4365.3	4365.9	4365.6	Beg. Ft. Em.
4357.4	4354.1	4352.6	4354.5	4354.2	4354.6	Def. Increase Em.
4352.0 4350.8			4349.9	4350.1	4350.7	Max. Em.
4342.2 4339.8			4341.6	4342.8	4341.6	Indef. Min., Abs. Lines.
4328.5	4328.0	4328.7	4329.7	4329.5	4328.9	Abs. line.
	4319.0	4320.4	4317.7	4318.1	4318.8	End. Em., Abs. Line.
4325.9						Abs. Line (Fe. 4326).
4320.9						Beg. Em. Bd. (ft.).
4301.0						Max. Em. Bd. (ft.).
4286.3						End Em. Bd. (ft.).
4249.5	4248.3				4248.9	Beg. Ft. Em.
4234.5						Max.
4228.0						Abs. Min.
4221.6	4222.3				4221.9	End Em. Abs.
4190.7						Beg. Em. (ft.).
4177.7						Abs. Min.
4162.1						End Em.
4123.3	4123.2		4125.4	4121.2	4123.3	Indef. Beg. Ft. Em.
4115.0	4115.1		4114.8	4114.3	4114.8	Def. Increase Em. Ab. Line.
4112.2 4110.1			4110.7	4107.5?	4110.7	Max. Em.
4101.7 4100.2		4101.6	4101.6		4101.2	Indef. Min., Abs. Lines.
4090.7	4090.0	4090.6	4091.3	4089.6	4090.4	Abs. Line, Def. End Em.
	4081.6	4082.3	4081.4		4081.8	Abs. Line, End Ft. Em.

MEASURES—*continued*

4892-3	4906	4914	4922	4923	Means	Remarks
3985.9	3983.4		3984.2	3983.0	3984.1	Indef. Beg. Em.
3978.7				3978.7	3977.9	Max. Em.
3976.3						
3968.5	3968.6	3968.7	3968.9	3968.7	3968.7	Abs. Line (H).
3959.1	3958.3	3957.5			3958.3	End Em., Abs. Line.
	3950.7	3950.2			3950.4	Abs. Line (Brd.).
3946.3	3950.7	3950.2			3949.6	Beg. Em. Bd.
3933.8	3933.8	3933.8			3933.8	Abs. Line (K).
	3922.0	3922.3			3922.2	Brd. Abs. Line.
		3914.9			3914.9	Brd. Abs. Line.
	3878.0	3878.4				Abs. Line.
	3870.4	3870.9				Abs. Line, End Em.
	3826.8					Abs. Line.

ABBREVIATIONS

Abs. —absorption
Beg. —beginning
Bd. —band
Brd. —broad
Def. —definite
Em. —emission
Ft. —faint
Indef.—indefinite
Max. —maximum
Min. —minimum

Besides the measures given above, measures of a number of sharp absorption lines used in determining the velocity of the absorbing atmosphere are given in the table of velocities below. A few other faint absorption lines, present for the most part in spectra 4892-3, were measured, but as they were very faint and uncertain, and could not be identified with any elements which could reasonably be expected to be present, and as some are likely due to photographic defects in the film, they have not been given in the tables*.

The different groups of emission and absorption lines and bands are separated by means of spaces in the preceding table, indicating as far as possible the connection of the measures.

Some of the data contained in this table has been further classified and grouped in the following table for the purpose of determining the normal wave

* At the time of writing, the work of Küstner and Giebeler on the identification of some of the absorption lines of the Nova with those of radium, and of Newall and Stratton with displaced enhanced lines had not appeared.

lengths of the sources of emission and absorption present. These two tables serve to show that although the character of the spectrum has changed materially, this is rather a change in the physical conditions producing the spectra than any change in constitution.

The wave lengths of the principal emission bands have been obtained by comparing the measures of the unknown bands with those of the bands which we definitely know are due to the β, γ and δ lines of hydrogen. If we examine the spectra and intensity curves of the three groups of observations in the accompanying figure we see that each known emission band in each group has definitely measured positions of certain criteria which may, on comparison with the positions in unknown bands, which are frequently faint and also overlap one another, enable the wave length of the source to be accurately determined. For example we find in the first group (plates 4892-3), the hydrogen emission, consisting of strong broad bands about 40Å wide with fairly definite edges and having a well-defined double maximum at the red edge about 10Å from the normal position of the line. In the second group (plates 4906, 4914), we have the emission bands shading off more or less gradually to the red but sharply limited on the violet side by a pair of strong absorption lines about 10Å apart and the nearest about 12Å to the violet of the normal position. In the third group (plates 4922-3), the emission is composed of a strong central band nearly 30Å wide, limited at least to the violet by an absorption line and with weaker strips 10Å wide on each side. There are traces also, especially in the first and last groups, of broad faint absorption not far from the normal positions of the lines.

Proceeding then to tabulate these criteria in parallel columns with the known wave lengths of the β, γ and δ lines opposite, we readily obtain the wave lengths of the unknown emissions from three sources by direct proportion, making allowance for the changes in width and distance as we proceed along the spectrum. We find the very curious relation previously found in Nova Persei*, that the widths and displacements of the bands are directly proportional to the wave lengths. The values obtained by these three methods are given in parallel columns followed by the weighted mean, the probable source and the true wave length.

* Campbell & Wright, Astrophysical Journal XIV, 276.

DETERMINATION OF WAVE LENGTHS

W.L. Known Bands	Def. Limits Em. Bands	Computed W.L.	Pair of Abs. Lines	Computed W.L.	W.L. from Max. and Min.	Weighted Mean W.L.	Source	Normal W.L.
	5036.5 5004.0	5019.0	5004.0 4994.0	5016.7	5016.3	5017.0	He	5016.0
	4996.4 4956.7	4975? 4971?				4973?	?	
	4940.6 4911.8	4925.1	4911.8 4900.7	4923.8		4924.3	He	4922.2
4861.5	4877.6 4847.9	4861.6	4847.9 4837.6	4861.0	4861.4	4861.3	H	4861.5
	4683.7 4609.5	4669.5 4621.5	4609.5 4599.5	4622.2	4629	4669.5 4624	? ?	
	4596.8 4571.5	4583.2	4571.5 4562.0	4583.5	4584	4583.5	?	
	4560.1 4538.4	4548.4	4538.4 4528.2	4550.8	4549.5 4545.5	4548.5	H?	4544
	4535.4 4506.0	4519.5	4510.7 4503.9?	4521.0	4522	4520.7	?	
			4459.5 4450.3	4471.2		4471.2	He	4471.7
4340.6	4354.6 4328.9	4340.7	4328.9 4318.8	4341.7	4340.6	4341.0	H	4340.6
	4320.9 4286.3	4302.2 4298.6				4300	?	
	4248.9 4221.9	4234.1			4227.0	4229.5	Ca?	4227
	4190.7 4162.1	4175.3			4176.5	4176	?	
4101.9	4114.8 4090.4	4101.6	4090.4 4081.8	4101.3	4100.5	4101.1	H	4101.9
	3984.1 3958.3	3970.2	3958.3 3950.4	3968.3		3969.3	H Ca	3970.2 3968.6
	3949.6 3922.2	3934.8	3922.2 3914.9	3931.5		3933.1	Ca	3933.8
			3878.2 3870.6	3887.8		3887.8	H	3889.1
			3826.8	3835.8		3835.8	H	3835.6

The foregoing table shows the unmistakable presence of the hydrogen series from H_β to H_η inclusive and of three lines of helium λ5016, 4922 and 4472. Although the computed wave lengths of the first two are slightly greater than the normal, this is not to be wondered at when their faintness and their position near the limit of sensitiveness of the plates is considered. The position of λ4472 for which no evidence of emission appears and which is computed only from the faint pair of absorption lines on plate 4914, agrees very closely with the normal and forms corroborative evidence that the other lines above mentioned are due to helium. There is a possibility that the line computed at 4548 may be due to the line 4544 of the additional hydrogen series and also that the faint band at 4229.5 may be due to calcium at 4227. No identifications which seemed probable have suggested themselves for the other lines and they are hence left unclassified. Of the 19 probable emission and absorption bands, we have 6 due to hydrogen, 3 to helium, 2, possibly 3, to calcium, and possibly 1 to the additional hydrogen series, leaving 6 totally unidentified.

It must not be forgotten, however, that we have a number of sharp absorption lines due to calcium, magnesium and iron only slightly displaced from their normal positions, probably by the motion of the star in the line of sight. The velocities given by each of these lines with the mean velocities of the plates and the corrected velocities with respect to the sun are given in the accompanying table.

VELOCITIES FROM SHARP ABSORPTION LINES

Element	Wave Length	4892		4893		4906		4914		4922		4923	
		Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.
Fe?	4529	2	+2.4	1	+6.3								
Mg.	4481	1	101.8	3	41.8					2	+10.6	1	+34.8
Fe.	4405					1	+37.9						
Fe.	4384					½	17.3						
Fe.	4326			2	46.1								
Fe.	4308					½	8.0						
H.	4102			1	41.3								
Ca.	3969	3	51.2	2	42.2	3	33.2	3	39.2	2	+29.3	2	+43.6
Ca.	3934	3	+51.7	3	+52.2	4	+35.1	3	+39.3				
W't'd Mean			+51.5		+48.2		+34.1		+39.2		+29.3		+43.6
Corr. to Sun			−29.1		−29.2		−29.5		−29.7		−29.9		−29.9
Rad. Vel			+22.4		+19.0		+ 4.6		+ 9.5		− 0.6		+13.7

The mean velocities are obtained from considering only the H and K lines, as they are the only ones that appear in all the plates and as they are by far the best and sharpest absorption lines. It is probable that the identification of the line 4529 as the iron line 4528.798 is not correct, for in order to make the velocity correspond with that given by the other lines the wave length would be only about 4528.1. The magnesium line seems also to give discrepant values, but as the line is faint and not very sharply defined on the spectra it is not surprising. There is, however, no doubt in my mind that there is sharp metallic, calcium, magnesium, iron absorption in the spectrum, produced presumably by a layer of metallic vapor surrounding the hotter incandescent material which gives rise to the emission and continuous spectrum.

It would appear as if this metallic atmosphere was varying in velocity, although I do not consider the evidence as quite sufficient to prove variability. Owing to trouble with the temperature case, there was a greater fall of temperature than desirable during some of the exposures, but as it was always in the one direction and compensated by numerous comparison exposures the relative error introduced should not be large. If we consider the velocity as constant and take the mean (giving the last two half weight) we find a velocity of recession of 12.4 kms. per second. The probable error of a plate then comes to nearly 6 kms. per second, which is much too high for the character of the lines measured and their internal agreement in the plates.

It therefore looks as if there might be a small range of velocity very much of the same character as that found in the class of spectroscopic binaries in which the diffuse lines give a high range of velocity and the sharp H and K are either constant or vary over a relatively low range.

The results obtained from the measures of six spectra of Nova Geminorum No. 2 photographed between March 18 and March 29 inclusive may be summarized as follows.

1. The spectrum has taken during this interval three separate and distinct though related forms. (a) A moderately strong continuous spectrum having superposed upon it a number of strong broad emission bands, maxima to red, accompanied by weak and faint absorption. (b) Continuous spectrum weaker than in (a) with strong emission bands shaded gradually to the red and sharply limited to the violet side by pairs of strong, moderately broad absorption lines.

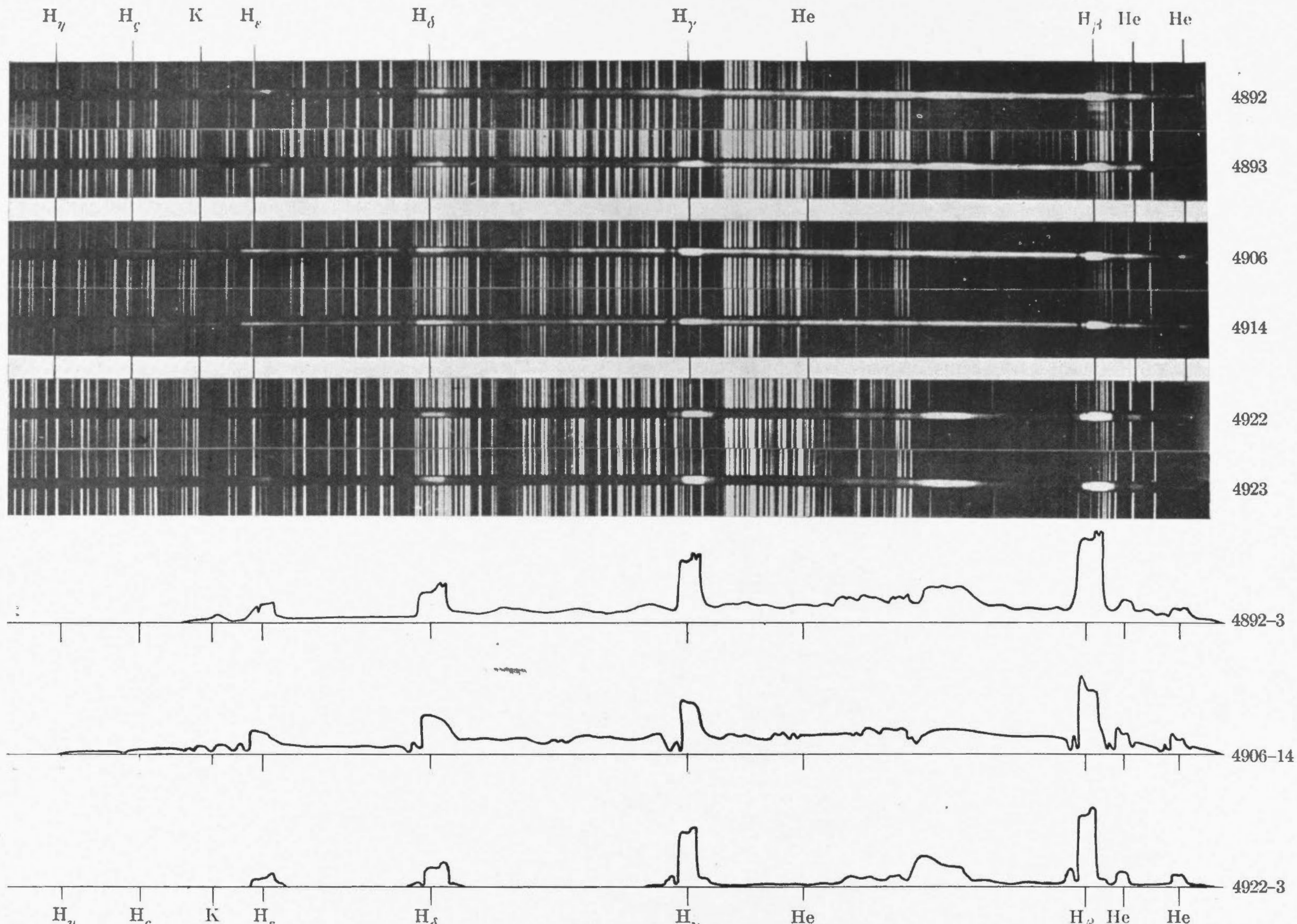
(c) Continuous spectrum very weak, emission bands strong and sharply limited at both sides; an absorption line to the violet side followed by weaker emission and about the same width of weak emission on the red side.

2. The measures of these spectra show six bands due to hydrogen, three to helium, two to calcium, two tentatively identified, six of unknown origin.

3. The measures of the sharp absorption lines of calcium, magnesium and iron indicate a mean velocity of recession of about 12 kms. per second. It is probable that this velocity is not constant but varies over a range of about 15 kms. per second.

There is little use in speculating about the physical cause of the peculiarities in this and other similar spectra. It seems most improbable that the widened emission and the largely displaced absorption lines are due to motion of the gases in the line of sight which would require velocities of the order of a thousand kilometres. There is, however, one phenomenon in accord with such an hypothesis, which is, that the width and displacement are proportional to and vary with the wave length, a condition which gives equal velocity for all lines. When we consider that this outburst, collision, explosion, or whatever it may have been, has set free sufficient energy to increase the light given out by this body, probably of the order of our sun in mass, thousands of times in a few hours, it seems hopeless from any terrestrial experience to attempt to explain the cause of the characteristic spectrum and of the changes that occur in it. We must perforce be content to carefully observe all possible phenomena in the hope that the mystery may eventually be at least partially cleared up.

DOMINION OBSERVATORY,
OTTAWA,
April, 1912.



Spectra and Intensity Curves of Nova Geminorum. Enlarged 5.2 times.