XI. *On the Causes which Produce the Phenomena of New Stars.*

By J. NORMAN LOCKYER, *F.R.S.*

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List of Diagrams.

I. Introduction.

In communications to the Society during the last three years I have produced evidence to show that many so-called stars, instead of being bodies like the Sun, are composed of swarms of meteorites. I have also discussed the spectroscopic evidence which suggests that such stars are increasing their temperature, and, taking a normal case of an undisturbed swarm, I have shown, by means of a temperature curve, the spectra produced by the same mass of meteorites in its evolution from a nebula to a condensed and nearly cold body. In considering this question the appearance of so-called "New Stars" was referred to, and it was suggested that such appearances might be due to the collision of meteor swarms or streams in space, an idea which I first put forward in 1877 with regard to Nova Cygni.

It became obvious then that a complete discussion of these phenomena would afford a valuable test of the general hypothesis, for the reason that such bodies, instead of going forward along the temperature curve, should go back as they cooled and became invisible. All the observations, therefore, have been brought together, and have been discussed from this point of view. These discussions form the subject matter of the present communication. The investigation has particular reference to the sequence of the spectra of Novæ, from their appearance to their diminution to invisibility. In the absence of spectroscopic observations the changes of colour that have been recorded afford a means of arriving at some idea of the physical constitution of the body observed.

For the purposes of this paper I define a Nova as a body which suddenly appears then diminishes its brightness and finally disappears *as a star*.

II. Early Views of the Origin of Novæ.

The first published views relating to the possible causes of the phenomena presented by stars suddenly coming into visibility we owe to Tycho Brahe and Kepler.

These were promulgated with reference to, and in explanation of, the new stars which appeared in 1572 and 1604.

It will be convenient to begin our consideration of the views in question by giving a condensed account of the observations which had suggested them.

The Nova of 1572 *observed by* Tycho Brahe.

This, the first Nova of which anything like a complete record exists, appeared in Cassiopeia, in 1572. The accompanying phenomena were minutely described by Tycho Brahe,* who first saw it on November 11, 1572. The Nova appeared destitute of nebulous surroundings, and only differed from other stars in the vivacity of its scintillations. When it was first observed, it appeared more brilliant than Sirius, α Lyræ, or Jupiter, and even rivalled the splendour of Venus at greatest brillancy, being, like Venus, visible in the daytime. At the beginning of December a diminution in brightness was noticed. This regularly continued until, in March, 1574, the Nova had disappeared.

The gradual diminution of the star's luminosity may be seen from the following photometric observations made by Tycho Brahe :—

November, 1572. Brighter than Sirius, α Lyræ, or Jupiter, and only comparable to Venus when most brilliant.
December, 1572. As bright as Jupiter.
January, 1873. Less bright than Jupiter.
February and March, 1573. Equal to a first magnitude star.
April and May, 1573. Equal to a second magnitude star.
July and August, 1573. Equal to a third magnitude star.
October and November, 1573. Equal to a fourth magnitude star
End of November, 1573. Equal to a fifth magnitude star.
Between December, 1573, and February, 1574. Equal to a sixth magnitude star.
March, 1574. Disappeared.

Curves have been plotted to show the decrease in magnitude of this and three other Novæ. These will be found on p. 439 of this paper.

Changes of colour accompanied the changes of brightness. When the star first became conspicuously visible it was white, like Venus and Jupiter. It then acquired a yellow colour which merged into red. In the first months of 1573, Tycho Brahe compared it to Mars and α Orionis, and considered it to be much like Aldebaran.

* Tycho Brahe, 'Progymnasmata,' lib. 2, p. 300.

Later on in the same year, and especially towards May, a leaden hue was observed, like that exhibited by the planet Saturn. This continued until January, 1574, when the colour appeared to become less clear and of a less pure whiteness as the star slowly disappeared.

The Nova of 1604 *observed by* KEPLER.

The famous Nova which appeared in 1604 is associated with the name of KEPLER, as that of 1572 is with TYCHO BRAHE. It was first observed on October 10, by BRONOWSKI, a pupil of KEPLER'S. The latter astronomer saw the Nova on October 17, and wrote a circumstantial account of his subsequent observations.

The following is a tabulated account of the estimations of its magnitude during the fifteen months that the star was visible :—

1604, October. Brighter than first magnitude stars, and also Saturn, Mars, and Jupiter.

1604, November 6. Could be seen at twilight, although Jupiter was not visible.

1604–5, December 24 to January 3. Greater that Antares, but less than Arcturus.

1605, March 20. Less than Saturn, but greater than third magnitude stars.

1605, April 21. Equal to a third magnitude star.

1605, August 12 and 14. Equal to a fourth magnitude star.

1605, September 13. Less than a fourth magnitude star.

1606, March. Disappeared.

KEPLER does not record a sequence of changes in colour like that undergone by the Nova of 1572, although he alludes to the yellow, saffron, purple, and red tints of the star when it was near the horizon. It will be seen from the following extract* that he refers to the scintillations as being like the colours reflected by the faces of a diamond, but this was also the case with TYCHO BRAHE'S Nova, and is distinct from the gradual colour changes of the latter star.

" Mini, qui potissimum respiciebam ad colorum Iridis varietatem, quos pro scintillationis alio atque alio habitu evomuit, placuit uti exemplo Adamantis multanguli, qui Solis radios inter convertendum, ad spectantium oculos, variabili fulgore revibraret : simul ad causam scintillationis, in Opticis meis allatam, alludere volui.

" De coloribus Mæstlinus planè mecum, eos ad momenta singula variari, ex flava mox croceam, è vestigio purpuream et rufam, *ut plurimum candidam videri, ubi ex vaporibus paulo altius elevetur.*"

Although many other Novæ have been observed, none have matched the splendour of those of 1572 and 1604, and of none have such circumstantial accounts been written. I now proceed to a statement of the explanation of the phenomena put forward by the respective observers.

* 'De Stella Nova in Pede Serpentarii,' Prague, 1606, p. 5.

TYCHO BRAHE's *Hypothesis.*

TYCHO BRAHE considered that new stars were formed from the cosmical vapour, which was supposed to have reached a certain degree of condensation in the Milky Way. In the words of this astronomer :—*

"Cœli materia ut subtillissima nostroque visui et planetarum circuitibus pervia, in unum tamen globum condensata compactaque, et lumine, si non proprio saltem solari, illustrata, hanc stellam effingere potuit. Quæ quoniam citra communem naturæ ordinem quasi monstrosa extitit, parem cum cæteris perseverantiam obtinere nequibat; veluti neque novæ ex elementis constantes generationes et monstra diu durant.

"Et quamvis in tota cælestis mundi vastitate materia pro conformatione alicuius stellæ ascititiæ, meo judicio abundè suppetat; tamen nusquam copiosius et pleniùs, quam juxta Viam Lacteam, quam substantiam quandam cælestem à materia reliquarum stellarum non discrepantem, sed diffusam certisque locis expansam, non in unùm corpus discretim, prout in stellis fit, conglobatam esse statuo : hincque factum judico quod nova hæc in ipso Galaxiæ margine constiterit."

It will be seen from the above extract from TYCHO BRAHE'S work that the fact that the Nova appeared on the edge of the galaxy was used to give weight to the hypothesis of stellar formation advanced by him. Indeed, some observers imagined they could see the *hiatus* or opening out of which the Nova came. The disappearance of the star was supposed to be due either to some action in itself or to its dissipation by the light of the Sun and stars.

When TYCHO BRAHE advanced the above theory, the tails of comets were looked upon as similar in constitution to the Milky Way.

Support of the Hypothesis by KEPLER.

KEPLER agreed with TYCHO in considering that new stars were created from the ethereal substance of which the Milky Way was composed. The circumstance that Mira Ceti, which was looked upon as a Nova, appeared in a part of the heavens distant from the Milky Way, was explained by saying that the nebulous material was not exclusively confined to the galaxy, as supposed by TYCHO BRAHE, but pervaded all space.†

A fact deemed of considerable importance was that both TYCHO BRAHE'S and KEPLER'S Novæ became suddenly and strikingly visible, and did not appear gradually to increase in brightness. Indeed, it was thought that all new stars must exhibit the maximum of brilliancy at their first appearance, and KEPLER went so far as to use the statement made by ANTONIUS LAURENTINUS POLITIANUS, that he had seen the Nova

* 'Progymnasmata,' p. 794.

† 'De Stella Nova in Pede Serpentarii,' KEPLER, pp. 110–112.

of 1604 increase in brightness, as an argument against his having seen the star at all. The following are the words used by LAURENTINUS :—

"Apparuit parva, et postea de die in diem crescendo apparuit magnitudine, et lumine non multò inferior Venere, superior Jove."*

NEWTON'S *View.*

The first Nova that attained any brilliancy, after that of 1604, appeared near β Cygni in June 1669, and was observed by ANTHELM.†

This Nova fluctuated in brightness between the 3rd and 5th magnitudes, and finally disappeared altogether. It is most probable that observations of this star drew NEWTON'S attention to the subject, and led him to the idea that "Novæ" were produced by the appulse of comets, thus propounded in 1686 in the 'Principia.'‡

"Sic etiam stellæ fixæ, quæ paulatim expirant in lucem et vapores, cometis in ipsas incidentibus refici possunt, et novo alimento accensæ pro stellis novis haberi. Hujus generis sunt stellæ fixæ quæ subito apparent, et sub initio quam maxime splendent, et subinde paulatim evanescunt. Talis fuit stella in cathedra Cassiopeiæ quam Cornelius Gemma octavo Novembris, 1572, lustrando illam cœli partem nocte serena minime vidit; at nocte proxima (Novem. 9) vidit fixis omnibus splendidiorem et luce sua vix cedentem Veneri. Hanc TYCHO BRAHÆUS vidit undecimo ejusdem mensis ubi maximè splenduit; et ex eo tempore paulatim decrescentem et spatio mensium sexdecim evanescentem observavit."

III. MODERN VIEWS.

In dealing with the period between NEWTON'S time and the present, I propose to give, as shortly as possible, some of the most important views expressed, during the last quarter of a century, by observers of the phenomena we are now considering.

ZÖLLNER, 1865.

According to the hypothesis advanced by ZÖLLNER,§ all stars, at a certain period of their formation, become covered with a cold, non-luminous crust. If the glowing mass bursts forth, the chemical combinations which have formed on the surface, under the influence of a low temperature, are again decomposed with a resulting development of considerable heat and light. Hence the great brilliancy of a new star must not be ascribed merely to the bursting forth of a glowing mass, but also to the combustion of the substances which form the shell.

* 'De Stella Nova in Pede Serpentarii,' KEPLER, p. 3.

† 'Phil. Trans.,' vol. 5, p. 2028.

‡ P. 525, Glasgow edition, 1871.

§ 'Photometrische Untersuchungen,' 1865, p. 251.

HUGGINS *and* MILLER, 1866.

Drs. HUGGINS and MILLER's observations of the Nova that appeared in Corona Borealis in 1866 led them to the following general conclusions :*

"It is difficult to imagine the present physical condition of this remarkable object. There must be a photosphere of matter in the solid or liquid state emitting light of all refrangibilities. Surrounding this must exist also an atmosphere of cooler vapours, which give rise, by absorption, to the groups of dark lines.

"Besides this constitution, which it possesses in common with the sun and the stars, there must exist the source of the gaseous spectrum. That this is not produced by the faint nebulosity seen about the star is evident by the brightness of the lines, and the circumstance that they do not extend in the instrument beyond the boundaries of the continuous spectrum. The gaseous mass from which this light emanates must be at a much higher temperature than the photosphere of the star, otherwise it would appear impossible to explain the great brilliancy of the lines compared with the corresponding parts of the continuous spectrum of the photosphere. The positions of two of the bright lines suggest that this gas may consist chiefly of hydrogen. . . . . The character of the spectrum of this star, taken together with its sudden outburst in brilliancy and its rapid decline in brightness, suggests to us the rather bold speculation that, in consequence of some vast convulsion taking place in this object, large quantities of gas have been evolved from it, that the hydrogen present is burning by combination with some other element and furnishes the light represented by the bright lines, also that the flaming gas has heated to vivid incandescence the solid matter of the photosphere. As the hydrogen becomes exhausted all the phenomena diminish in intensity and the star rapidly wanes."

JOHNSTONE-STONEY, 1868.

In a paper on the physical constitution of the sun and stars, Mr. JOHNSTONE-STONEY, in 1868, discussed the origin of double stars. He then remarked† that the astonishing phenomena witnessed in T Coronæ were precisely what should arise towards the end of a process he describes. This process may be understood from the following quotation :—

"The stars having been intensely heated by previous perihelion passages, and having begun to shrink, would, at ordinary times, present a spectrum subdued by an abundance of very dark lines; but immediately after one of the last occasions upon which their atmospheres brush against one another, the outer constituent of their atmospheres [hydrogen] and the outer constituent alone, would be raised by the friction to brilliant incandescence, which would reveal itself by the temporary sub-

* 'Roy. Soc. Proc.,' vol. 15, p. 148.

† 'Roy. Soc. Proc.,' vol. 17, p. 53.

stitution of four intensely bright for four dark dydrogen lines in a spectrum which everywhere else continues to be filled with dark lines. And, moreover, these dark lines would for a while be rendered faint by the fierce heat radiated upon the outer parts of the atmosphere of each star by its companion."

VOGEL, 1877.

Observations of the new star in Cygnus (1876–77) led Professor VOGEL to make the following remarks :—*

"It is generally supposed that the bright lines in some star spectra are due to gases which burst out from the interior of the luminous body at a temperature higher than the surface, as similar lines are occasionally seen in the spectra of sun-spots, and are caused by the eruption of incandescent hydrogen from the hot interior over the cooler surface of the spot. But this is not the only explanation. It may be assumed that the outer shell of a star, consisting of glowing gases, as in the case of our sun, has a lower temperature than the nucleus, although it is at a relatively high temperature.

"On the first supposition, it is impossible for the appearance to last for any length of time. The gas bursting forth from the heated interior would communicate part of its heat to the cooler surface, thus raising the temperature of the latter until the difference of temperature between the incandescent gas and the surface is insufficient to produce the bright lines, which consequently disappear.

"This theory satisfactorily explains the apparition of so-called *new* stars, having bright lines in their spectra, and which suddenly appear and speedily disappear altogether or lose most of their brilliancy, if ZÖLLNER's hypothesis be accepted as a further explanation."

It will be seen that VOGEL advanced no new hypothesis, but supported that of ZÖLLNER by spectroscopic observations.

LOHSE, 1877.

Dr. LOHSE advanced a theory to account for "new stars," founded upon his observations of Nova Cygni.† His suggestions are summed up as follows :—

(1.) "The lighting up of new stars may probably be looked upon as the result of the innate affinity of chemical matter.

(2.) "The conditions and manner of illumination may be regarded as follows :—By the progressive cooling of the mass of a luminous body (fixed star) which consists of heated vapours and gases, an atmospheric envelope is erected which absorbs the light so much, that the star cannot be seen at all, or only very faintly, from the earth. As this body continues to give out heat, at length the degree of coolness is reached which

* 'Berlin Akad. Monatsberichte,' 1877, p. 256.

† 'Berlin Akad. Monatsberichte,' 1877, p. 826.

is necessary for the formation of chemical combinations. The greater portion of the body is composed of elements which then combine, producing, by their combination, heat and light, and thus making the star visible to a great distance, and for a long or short space of time."

LOCKYER, 1877.

In this year, discussing the phenomena of Nova Cygni, I advanced the view that meteoritic collisions were, in all probability, the cause of them. This will be discussed in a subsequent part of this communication.

MONCK, 1885.

Mr. W. H. S. MONCK suggested,* in relation to the new star in Andromeda, that, "as shooting-stars are known to be dark bodies rendered luminous for a short time by rushing through our atmosphere, new stars are dark (or faintly luminous) bodies which acquire a short-lived brilliancy by rushing through some of the gaseous masses which exist in space."

IV. THE METEORITIC THEORY OF THE ORIGIN OF NOVÆ.

General Statement.

In a former communication to the Royal Society† I stated the conclusions I had arrived at as a result of spectroscopic work as follows: "New stars, whether seen in connection with nebulæ or not, are produced by the clash of meteor swarms, the bright lines seen being low temperature lines of elements, the spectra of which are most brilliant at a low stage of heat." This general theory, however, does not exclude other causes, such as the sudden illumination produced by collisions of two dark bodies, but I pointed out that no case of this kind has happened within human ken. This hypothesis was first, I think, advanced by myself in 1877, when I wrote as follows in connection with Nova Cygni:‡ "Of all the lines chronicled by CORNU and VOGEL, only one remains, that, namely, which the latter observer showed to be constantly increasing in brightness, while all the rest were waning, and which, moreover, as VOGEL also distinctly showed, is coincident in position in the spectrum with that observed in the majority of the nebulæ.

"It should have been perfectly clear to those who thought about such matters, that the word 'star' in such a case is a misnomer, from a scientific point of view, although no word would be better to describe it in its popular aspect. The word is a misnomer,

* 'Observatory,' October, 1885.

† 'Roy. Soc. Proc.,' vol. 43, p. 154.

‡ 'Nature,' vol. 16, p. 413.

for this reason. If any star, properly so called, were to become a 'world on fire,' were to 'burst into flames,' or, in less poetical language, were to be driven either into a condition of incandescence absolutely, or to have its incandescence increased, there can be little doubt that thousands or millions of years would be necessary for the reduction of its light to the original intensity.

"Mr. CROLL has recently shown that if the incandescence observed came for instance from the collision of two stars, each of them half the mass of the sun, moving directly towards each other with a velocity of 476 miles per second, light and heat would be produced which would cover the present rate of the sun's radiation for a period of 50,000,000 years.

"A very different state of affairs this from that which must have taken place in any of the Novæ from the time of TYCHO to our own, and the more extreme the difference, the less can we be having to deal with anything like a star properly so called.

"The very rapid reduction of light in the case of the new star in Cygnus was so striking that I at once wrote to Mr. HIND to ask if any change of place was observable, because it seemed obvious that if the body which thus put on so suddenly the chromospheric spectrum were single, *it might only weigh a few tons or even hundredweights*, and being so small might be very near us. We are driven, then, from the idea that these phenomena are produced by the incandescence of large masses of matter because, if they were so produced, the running down of brilliancy would be exceedingly slow.

"Let us consider the case, then, on the supposition of small masses of matter. Where are we to find them? The answer is easy: in those small meteoric masses which an ever-increasing mass of evidence tends to show, occupy all the realms of space.

"The Nova now exists as a nebula, so far as its spectrum goes, and the fact not only goes far to support the view I have suggested as against that of ZÖLLNER, but it affords collateral evidence of the truth of THOMSON and TAIT's hypothesis of the true nature of nebulæ.

"The nebular hypothesis in its grandeur and simplicity remains untouched by these observations, the facts, so far from being in direct opposition to it, help us, I think, all the better to know exactly what a nebula is.

"There is another point of extreme interest to the spectroscopist, if we accept the bright line observed in the star by Dr. COPELAND and others to be veritably the chief nebula line.

"It is clear from Dr. VOGEL's diagram, that this line brightened relatively with each decrease in the brilliancy of the hydrogen lines. On December 8th, 1876, it was much fainter than F, while by March 2nd, 1877, F was a mere ghost by the side of it. On any probable supposition the temperature must have been higher at the former date."

The Origin of the Mixed Spectra of Novæ.

The discussion of the observations which have been made of the changes that take place in the spectra of new stars, has already shown that the sequence of phenomena is strikingly similar to that which occurs in cometary spectra after perihelion passage. In general, however, there will be a difference : namely, that in comets there is usually only one swarm to be considered, whereas in new stars, there are two, which may or may not be equally dense. In new stars, we have accordingly the integration of two spectra, and the spectrum we see will depend upon the densities and relative velocities of the two swarms. At one part of the mixed swarm the temperature must generally be considerably higher than at another, in consequence of the greater number of collisions occurring locally, and the temperature would be lowest where the outliers were engaged.

In new stars, therefore, it is possible for us to have the radiation spectra of vapours corresponding to sparse swarms of meteorites (nebulæ, bright-line "stars," and comets away from perihelion), and the mixed radiation of carbon, with the fluting absorption of metallic vapours, corresponding to bodies of Group II., and to comets nearer perihelion. That is to say, we may have the radiation lines of hydrogen and fluting of magnesium at 500, *plus* the radiation of carbon and fluting or line absorption of manganese, lead, iron, &c., a condition which cannot occur when only a single swarm is in question.

The mixed spectroscopic phenomena, which should be seen on the collision of two swarms, were noted in my paper of November, 1887,* as follows :—"We shall, in fact, have in one part the conditions represented in Class III*a*., and in the other, such a condition as we get in γ Cassiopeiæ."

In the present paper I give detailed discussions of all the Novæ which have been spectroscopically examined, and the results fully bear out these views.

The Relation between Novæ and Variables of Group II.

If the two swarms which produce a new star by collision are such that the mean distance between the meteorites in the resulting "mixed swarm" is about equal to that between the meteorites in a body of Group II., say α Orionis, mixed radiation of carbon and metallic fluting absorption will preponderate in the spectrum observed. At the same time, the sparser portions of the swarms give us hydrogen radiation. This was the state of things in Nova Coronæ, a detailed discussion of which is given later on. The general spectrum observed was one similar to that of α Orionis, but in addition, the presence of bright hydrogen lines was noted. This is a condition which cannot occur at any stage in the condensation of a single swarm, because a swarm dense enough to give the α Orionis type of spectrum would be too dense to give hydrogen radiation. In a dense swarm absorption preponderates, whilst in sparse

* 'Roy. Soc. Proc.,' vol. 43, p. 147.

swarms radiation preponderates, the interspaces being flooded usually with incandescent vapours of magnesium and hydrogen.

In variables of the Mira type, we have almost a reproduction of the conditions of Nova Coronæ. As I suggested in the Bakerian Lecture, the variability in this class of stars is in all probability due to a swarm of meteorites revolving in a more or less elliptical orbit around a central swarm, the maximum luminosity occurring at periastron passage. At maximum, therefore, in such a variable, the luminosity proceeds from a mixed swarm, exactly in the same way as in a new star. At the maxima of Mira and other long-period variables, bright hydrogen lines have been observed, although the spectra are of the Group II. type.

In the detailed discussions which follow, Nova Orionis has been omitted, as it has turned out to be nothing more than a long-period variable of Group II.

V. Discussion of the Spectra of Novæ.

Nova Coronæ, 1866.

The spectrum of this star was observed on several dates by Messrs. Huggins and Miller, Wolf and Rayet, and Stone and Carpenter. The observations of Huggins and Miller were made on May 16, 17, 18, 19, 21, and 23; those of Wolf and Rayet on May 20; and those of Stone and Carpenter on May 19, 20, 23, 24, 28, and June 7. There is a general agreement as to the positions of the lines determined by the different observers, and the principal difference observed as the star faded was simply a diminution of the number of lines.

In their first observation on May 16, Messrs. Huggins and Miller* noted four bright lines and suspected a fifth. Two of these were found by direct comparison to be the C and F lines of hydrogen, but the positions of the other two were only roughly plotted on a diagram. There are not sufficient data for accurate reduction of the wave-lengths of these lines, but by a curve they have been found to be at approximately 468 and 473. Of the more refrangible of the two it is remarked: "The appearance of this line suggested that it was either double or undefined at the edges." The fifth line suspected was probably not far from G of the solar spectrum, and the presence of C and F make it highly probable that this was the hydrogen line at G.

In addition to these bright lines, many absorption lines and bands were observed. These absorptions were evidently very similar to those seen in stars like α Orionis. This was noted by Messrs. Huggins and Miller, and I have since compared those in the blue end of the spectrum with the lines photographed in α Orionis by Professor Pickering, who kindly furnished me with the data necessary for the reduction to wave-lengths. This shows a very close relation between the two spectra. The

* 'Roy. Soc. Proc.,' vol. 15, p. 147.

spectrum was again observed by Messrs. HUGGINS and MILLER on May 17 and 19, but no remarkable difference was noted.

On May 19, the spectrum was also observed by Messrs. STONE and CARPENTER.* Four bright lines were seen, but only three of them were fixed by measurements. The position of the fourth was approximately determined by estimation. One of the lines was undoubtedly F, and the wave-lengths of the others, as deduced from a curve, I find to be about—

501	Position of line estimated.
471	,, ,,
467	,, ,,

The data for reduction, however, are quite insufficient to give anything like accurate results. The C line was not recorded.

In the account of his observations of Nova Cygni, VOGEL refers to the observations† of STONE and CARPENTER; he reduced the positions of the lines to wave-lengths with the following results:—

502
467
463

He points out, however, that on account of insufficient data, these cannot be regarded as accurate.

The line 500 was seen only by Messrs. STONE and CARPENTER. The other two lines are, in all probability, identical with those observed by Messrs. HUGGINS and MILLER, for which I have determined the wave-lengths 468 and 473. Traces of absorption lines were also observed, thus confirming the observation of Messrs. HUGGINS and MILLER. Another observation was made by Messrs. STONE and CARPENTER on May 20, but to them the spectrum did not differ from that of the previous day.

MM. WOLF and RAYET,‡ however, made an observation of the spectrum of this star on the same day. They record: "The light of the new star gives a complete, very pale spectrum, on which are seen a certain number of brilliant bands. The brightest and largest of these bands appeared in a continued manner almost at the edge of the yellow and the green. It is preceded on the yellow side by a rather dark space, then by a bright, but weak line. A third line, which seems to correspond to D, is seen in the yellow, pretty bright, and towards the orange. Then, after the brightest line towards the violet end, the green is seen well marked, then a darker space a little darker than we spoke of before, and another line as bright as the principal band.

* 'R. Astron. Soc. Monthly Notices,' vol. 26, p. 295.
† 'Berlin Akad. Monatsber.,' 1877, p. 243.
‡ 'Comptes Rendus,' vol. 62, p. 1108.

The rest of the spectrum is pale, with ill-defined edges, and with nothing marked about it that we could distinguish."

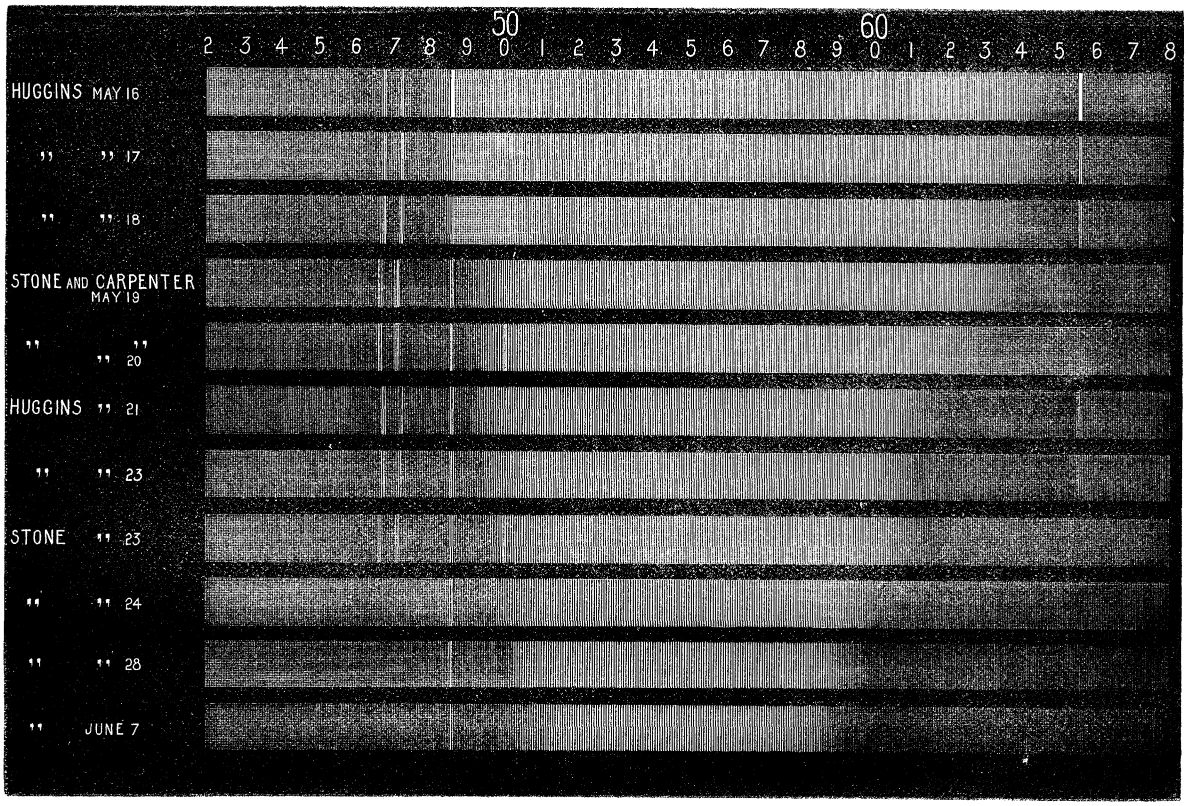
It is greatly to be regretted that the positions of the lines were not measured. Without these it is quite impossible to connect them with the other observations. It is remarkable that the line in the yellow, which may have been D or D_3, was not recorded by any of the other observers.

Messrs. HUGGINS and MILLER again observed the spectrum on May 21 and 23. On these dates the bright lines appeared more brilliant than on former occasions, owing to the dimming of the continuous spectrum.

On May 23 Mr. STONE again saw the four lines which he had observed previously, but on May 24 and 28 and June 7, he was only able to see the F line. It was the opinion of both Mr. STONE and Mr. CARPENTER that the bright lines and the continuous spectrum faded at the same rate.

All these observations, with the exception of the one by WOLF and RAYET, are shown on the accompanying map.

Fig. 1.



Spectra of Nova Coronæ.

The observations are also shown in another way in the following table :—

Date.	Observer.						Remarks.
May 16, 17, and 19	Huggins and Miller	Hγ suspected	468, 473	486	..	Hα (656)	468, 473 deduced from the curve, the former being "either double or undefined at the edges." Many absorption lines seen
May 19 and 20	Stone and Carpenter	..	467, 471	486	501	..	467, 471, 501, determined by curve. Absorption lines also seen
May 20	Wolf and Rayet	..	..	..	..	..	Bright lines seen but not measured
May 21 and 23	Huggins and Miller	Hγ suspected	468, 473	486	..	Hα (656)	The lines appeared more brilliant than before
May 23	Stone	..	467, 471	486	..	..	
May 24, 28, and June 7	Stone	..	..	486	..	..	The F line was "desperately faint"
Suggested origins		H (434)	Carbon (468–474)	H (486)	Mg (500)	H (656)	

It will be seen that the F line was constantly recorded, whilst C was only observed by Messrs. HUGGINS and MILLER. The two lines in the blue, near 468 and 473, were constantly seen up to May 23, when the star was of magnitude 7·2. The line near 501 was only seen by Messrs. STONE and CARPENTER; it was not recorded after May 23. The *dark* lines are left out in the map.

There can be no question as to the origin of two of the lines—that in the red and that in the blue-green. They were undoubtedly due to hydrogen. The line near 501 was, in all probability, the same as that which was seen to brighten in Nova Cygni as the star faded. This was also suggested to VOGEL in referring to his observations of Nova Cygni. There is other evidence to show that this was identical with the chief line in the spectrum of the nebulæ.

The two lines in the blue present a little more difficulty. The more refrangible one near 468 may have been due to the carbon fluting, which, under certain conditions, has its maximum intensity about 468,* especially as Dr. HUGGINS stated that its "appearance suggested that it was either double or undefined." The one near 473 was probably the less refrangible edge of the same compound fluting of carbon.

In some of the observations of comets (*e.g.*, Comet III., 1881, on June 28) the blue band has been recorded with two maxima, one at 468 and the other at 474. This strengthens the view that the two lines seen in Nova Coronæ may have had the same origin. In comets, the more refrangible one is the least defined, and this was also the case in the Nova. The two maxima were also seen in Nova Cygni (see p. 415), but in that case the less refrangible one was only visible for a short time. I have very little doubt that both in comets and Novæ the two maxima were due to carbon. In the laboratory experiments in connection with this point photographs have been obtained, which show the compound group with a bright maximum of intensity about 468, at the same time leaving the least refrangible maximum (474) fairly bright, and the two intermediate ones much weaker. It is not difficult to understand that under difficult conditions of observation such a group should be mapped as two lines, one corresponding to the maximum at 468 and the other to that at 474.

Whatever the origin of the two lines, the fact of their being common to comets and Novæ is very significant.

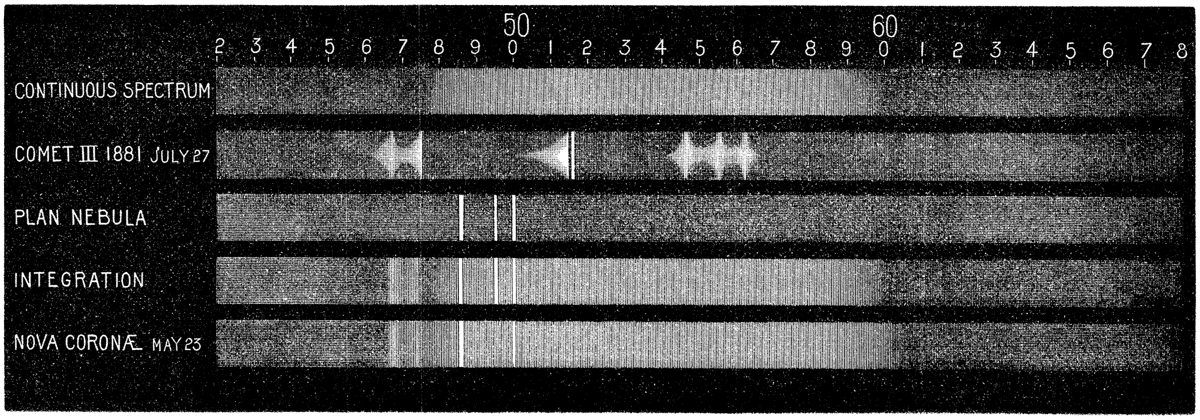
It is rather remarkable that in Nova Coronæ the F line should remain visible for a longer time than the line near 500, because in Nova Cygni it died away first, leaving 500 very bright to the end. It must be remembered, however, that the later observations by Mr. STONE were made under very difficult conditions, the F line itself being "desperately faint," so that the 500 line may very well have been overlooked. If the observations could have been continued longer, it is not impossible that the line 500 might have been seen after F. The 500 line would also be more liable to be masked by continuous spectrum than the F line, so that the presence of a brighter continuous

* 'Roy. Soc. Proc.,' vol. 45, p. 167.

spectrum than in Nova Cygni may explain why F should be seen last in one case and 500 in the other.

I have already pointed out that in Novæ we have not simply to deal with one state of condensation of a swarm. At least two swarms are concerned, and these are not necessarily of the same density. It therefore becomes interesting to attempt to reproduce the spectrum of a Nova by integrating the spectra of two or more swarms of meteorites, each of which is at a stage of condensation different from the others. Such an attempt is shown in fig. 2, where the spectra of COGGIA's comet and the

Fig. 2.



Integration of the spectra of COGGIA's comet and planetary nebula compared with spectrum of Nova Coronæ.

planetary nebula G.C. 4373 are integrated. The comet at this stage showed the carbon spectrum, the blue band having two maxima. In the resulting integration the green cometary bands are almost masked by continuous spectrum, whilst the blue one remains visible, exactly as it does in the bright-line stars.* The nebula line 495 was probably too faint to be detected. The line 500 was also faint, and this and 495 were probably partly masked by the continuous spectrum, which would be slightly brighter in that part of the spectrum than at F. The continuous spectrum would be brightened by the collision of two swarms, and hence it is necessary to add continuous spectrum in the integration.

The observed changes of magnitude of this Nova during its period of visibility were as follows :—

May	12	. . . 2
,,	13	. . . 2·3
,,	14	. . . 3
,,	15	. . . 3·4
,,	16	. . . 4·2

* 'Roy. Soc. Proc.,' vol. 44, p. 33.

May	17	4·7
,,	18	5
,,	19	5·3
,,	20	6·2
,,	21	6·3
,,	22	7·3
,,	23	7·5
,,	24	8·4
,,	27	8·5
,,	28	8·3
,,	29	8·5
June	7	8·9

Nova Cygni, 1876–77.

This star was discovered by SCHMIDT at Athens on November 24, 1876. Its magnitude was then 3·0, and its colour a reddish-yellow. On December 5 the magnitude was 5·9, and it steadily diminished in brightness, until on March 10 its magnitude was 8·3. In 1882 Dr. COPELAND found that it had decreased to the 14th magnitude.

The spectrum of the star was observed on several occasions by VOGEL, LOHSE, COPELAND, and CORNU. The earliest spectroscopic observations appear to have been made by M. CORNU, who recognised bright lines in the spectrum on December 2, but was unable to make any measurements. Two days after, a more complete examination of the spectrum was made, and on this occasion the positions of the lines were measured. Eight lines were bright enough to be recorded, but no dark lines were seen. He says,* "The dark lines, if they exist, must be very fine, and must have escaped me, on account of the very feeble light of the star." VOGEL suggests that CORNU did not see the dark lines because he employed too much dispersion. The following are the wave-lengths of the bright lines which he observed, the Greek letters indicating the relative intensities, α being the brightest :—

α	δ	γ	β	ζ	η	θ	ϵ
661	588	531	517	500	483	451	435.

The lines α, δ, η, and ϵ were doubtless C, D, F, and G respectively, and M. CORNU points out that the remaining lines, with the exception of the one near λ 500, are nearly coincident with the lines which occur most frequently in the spectrum of the solar chromosphere. The line γ is regarded by M. CORNU as possibly coincident with the coronal line 5315·9. β he believed to correspond with the b lines of mag-

* 'Comptes Rendus,' vol. 83, p. 172.

nesium. He further states that "the feeble band θ corresponds also to a band, $\lambda = 447$, of the chromosphere; one is thus led to think that the line δ corresponds rather to the bright line of the chromosphere, $\lambda = 587$ (helium), than to that of sodium, 589. If this interpretation be accurate, the bright lines of the spectrum of the star comprehend inclusively the brightest and most frequent lines of the chromosphere."

In the diagram of the spectrum which accompanies M. CORNU'S paper, there are shown three maxima of brightness which are not referred to in his description. These have been reduced by a curve, and their wave-lengths found to be approximately 546, 563, and 635. These agree very well with lines observed by VOGEL.

The observations of VOGEL and LOHSE were made independently with the Berlin refractor. LOHSE'S chief object was "to study the total character of the star's spectrum and to note the changes undergone by it in the course of its appearance." He made no measurements, but simply gave diagrams, showing approximately the relative positions and appearance of the various lines and bands. VOGEL, on the other hand, gave particular attention to the determination of wave-lengths, but he also made drawings indicating the general appearance of the spectra on different dates.

LOHSE'S observations commenced on December 5, and, referring to this observation, he says :— *

"Particularly striking was a broad bright line in the red, bordered towards the yellow by a broad dark band, which ran towards the yellow and broke off into lines showing the red ground between them and giving the band a brownish appearance. I saw, besides, several bright spots in the yellow, green, and blue, but, on account of their width, I regarded them, not as bright lines, but as spots free from lines in the continuous spectrum. A bright spot in the blue-green looked particularly striking, on account of its being bordered by a broad very dark band running towards the blue.

"The spectrum was traversed by numerous bands.

"The positions of the lines were based not on measurement but on estimation."

VOGEL'S observation of the star on this date, December 5, is not mapped with the others given by him, but there appears to be little difference between his observation and that of Dr. LOHSE; he says :—†

"The spectrum was very bright, with numerous dark bands, the most striking of which were a very dark one in the green and a very broad one in the blue. . . .

"Besides the dark lines and bands several bright lines were seen in the spectrum, one of which, in the red, was specially striking on account of its brilliancy; another very bright line was on the border of the green and blue, and two were in the blue. In the yellow and green there were some bright lines or bands, but I could not ascertain whether they were really bright lines or only places in the spectrum which appeared bright by contrast with the dark absorption bands. . . .

"For the two parts in the blue the wave-lengths 474 and 470 were estimated, the

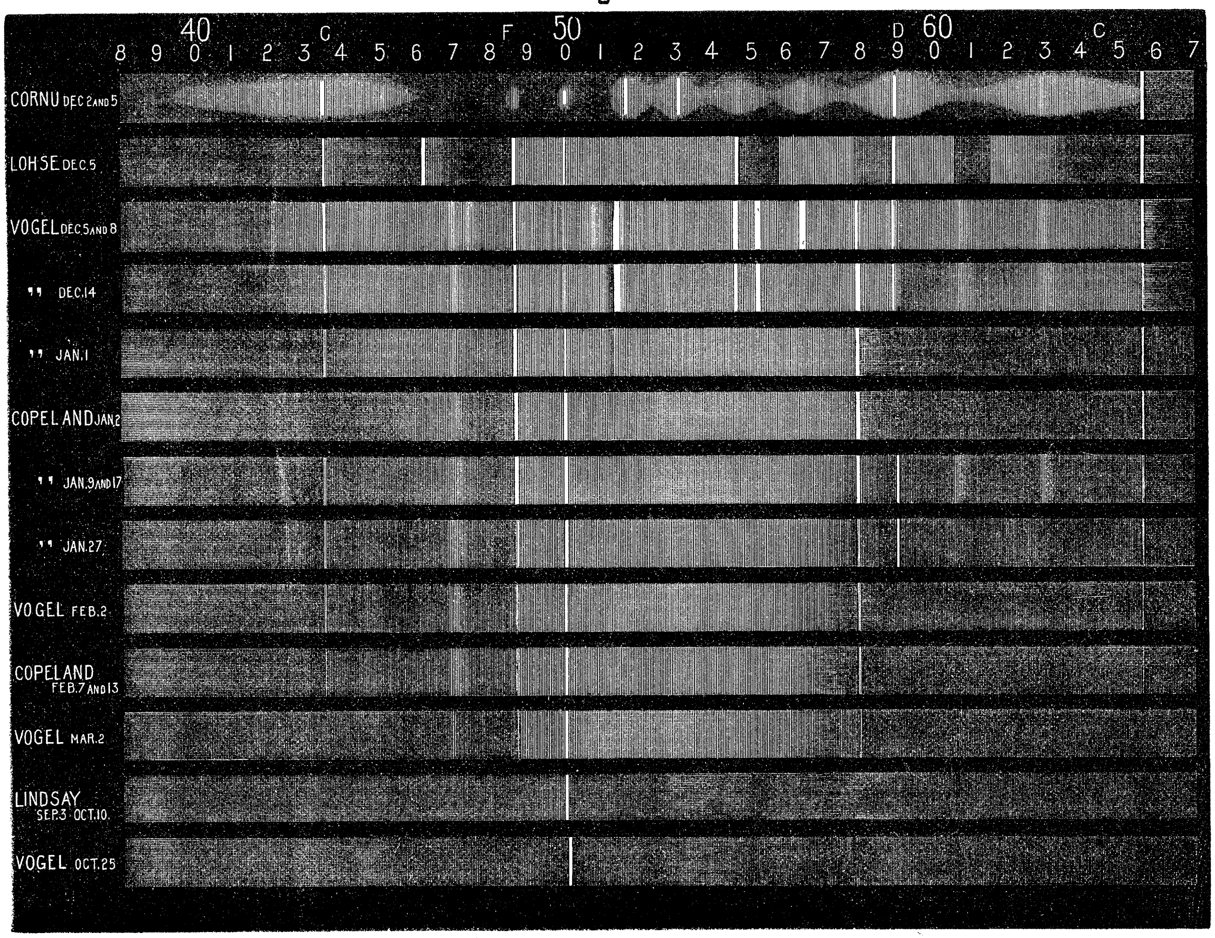
* 'Berlin Akad. Monatsber.,' 1877, p. 826.

† 'Berlin Akad. Monatsber.,' 1877, p. 243.

bright lines or bands found in the green were estimated at the wave-lengths 512 and 498."

VOGEL's observation of December 5 appears to differ mainly from LOHSE's in the blue end, LOHSE only recording one line in place of the two observed by VOGEL near λ 474 and 470. The subsequent confirmations of these lines by VOGEL, however, can leave very little doubt as to their presence. VOGEL's observation of this date was not quite completed on account of clouds.

Fig. 3.



Spectra of Nova Cygni.

LOHSE's results are only represented by rough diagrams, and it is not possible to accurately reduce to wave-lengths the positions of the lines which he observed. By comparison with VOGEL's observations, however, it is not difficult to determine the lines which he observed. There were certainly C, D, F, and G. The line in the green which brightened as the star faded was undoubtedly the line near λ 500, which is seen in the spectra of nebulæ. Another bright line between 500 and D is found on reduction by a curve to be near λ 546, and this agrees with one of the lines observed by VOGEL.

Instead of the two lines 470 and 474, observed by VOGEL, LOHSE only records one, and this is found to be near λ 462. In his later observations VOGEL only recorded one line in place of the two previously observed, at a mean wave-length of 467.

These observations are shown on the map, fig. 3, and it will be seen that there is really no great divergence. All three observers agree as to the chief lines.

The next observation was made by VOGEL on December 8. The hydrogen lines C, F, and G were again seen, and, in addition, other lines were measured. The bright line less refrangible than F was estimated to be near λ 498, and three other lines in the green near 527, 514, and 508.

Two lines in the yellow had their wave-lengths estimated at 588 and 570,* but these depended on one measurement only, and their positions are, therefore, somewhat uncertain. With regard to the line near 588, VOGEL says :—

"The first of these lines agrees very closely with D_3 (λ 587·5), and it would not be surprising if this line appeared bright in the spectrum with the hydrogen lines." The two lines in the blue, previously estimated at 470 and 474, were repeatedly seen, but not measured. A broad faint line was seen in the violet, and VOGEL suggests that this was the hydrogen line at G (λ 434). He also points out that although the line 514 agrees most nearly with the magnesium line *b* (wave-length for the middle, 517·5), the difference between the lines is such that the probability of the magnesium lines appearing bright in the star's spectrum is very small.

Further observations were made by VOGEL on December 14, 22, 26, 27; and January 1, 2, 6, 16, 17, and 18; February 2, 17; March 2 and 10. All these observations for which the description is complete, are shown in fig. 4, and it will be seen that the principal changes are:—(1) a general diminution in the number and brightness of the lines; and (2) the brightening of the line in the green near λ 500 as the other lines disappeared.

VOGEL thus summarises the lines which he observed, pointing out that the difficulty of the observations and the unfavourable weather prevented very exact measurements.

(1) The hydrogen lines, $\left.\begin{matrix} H\alpha \\ H\beta \end{matrix}\right\}$ certainly.

$H\gamma$, most probably.

(2) A line of the wave-length 499 ± 1 max. This line comes into pretty close agreement with the brightest line of the nitrogen spectrum under ordinary pressure; it is the same line which is brightest in the spectrum of the nebulæ.

(3) A faint line at λ 580.

(4) A similar one at 467. (This agrees pretty well with a group of lines close together in the spectrum of air.)

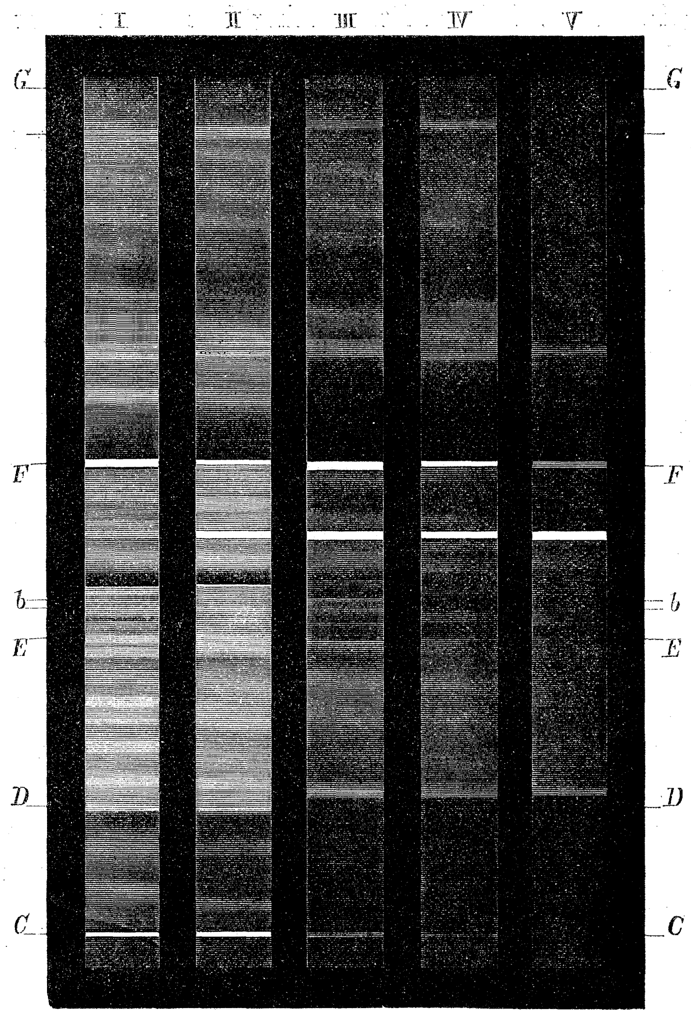
(5) There were also bright lines seen in the region of *b* and E, but nothing certain could be ascertained about their position. At the first observation on December 5, two lines were measured in the blue (474 and 470); these were again seen on

* This is evidently a misprint for 580. No line is shown at 570 in the map, but one at 580 is afterwards referred to.

December 8, but in later observations only the second was perceived as a faint band (λ 467).

For further details, the drawings must be referred to, for, as VOGEL states, they show several details which can hardly be put into words.

Fig. 4.



VOGEL's observations of Nova Cygni.

VOGEL refers to CORNU's observation, and states that he cannot agree that "the atmosphere of the star possesses exactly the same composition as that of the chromosphere of the sun." His chief objection to this view is that the line near 500, which is not in the chromosphere, was distinctly seen along with other bright lines in the star's spectrum, and eventually became the strongest line.

Dr. COPELAND* also made a large series of observations, but he was not able to commence before January 2, 1877. He continued his observations to February 16, and recommenced on September 2.

On January 2, five bright lines were recorded. The measurements show that two

* 'COPERNICUS,' vol. 2, p. 102.

of these lines were the C and F lines of hydrogen. Two series of measurements were made, and for the other three lines the following wave-lengths were determined :—

1st series.	2nd series.	
577·9	579·0	Bright band fading rapidly on both sides.
502·4	505·1	Bright well-defined lines.
463·4	466·8	Faint band.

There can be little doubt that these correspond to the lines measured by VOGEL at 580, 499, and 470 (some measures 467).

On January 9, seven lines were measured, and it was further stated that "the space between the red line (C) and the next one (D) was certainly columnar, and probably contained two maxima." These were probably identical with those seen by VOGEL, and they have therefore been inserted in the map (fig. 3).

The following summary of results is given by Dr. COPELAND :—*

Number of line.	1	1*a*	2	3	4	5	7
Date.							
1877, Jan. 2	657·8	..	579 9	502·4	486 1	463·4	
" " 2	654·7	..	579·0	505·1	488·4	466·8	
" " 8	656·2	..	..	502·9	486·1	464·8	
" " 9	656·2	589·5	575·9	500·7	486·1	461·6	437·6
" " 27	..	..	..	500·8	486·1	461·5	
" Feb. 13	681·5	..	574·9	502·3			
" " 13	670·8	..	574·9				
" " 13	..	..	574·0				
Adopted means	656·2	589·5	577·5	502·3	486·1	463·5	437·6
Mean error	..	..	± 1·1	± 0·8	..	± 1·0	

The star was not again observed until September 2, 1877 (the estimated magnitude being 10·5), when the startling fact was at once apparent that the spectrum was restricted practically to a single line. The measurements show that this was the line near 500. On September 6, it was observed that in addition to the chief line there were traces of one or two lines on the violet side of the chief line, but very close to it. On this date it was noted that the star did not give a sharp image, but that the "extreme diameter could not be above 2 seconds or $1\frac{1}{2}$ seconds." On October 1 the star was examined with a view to detecting any very faint continuous spectrum, but nothing of the kind was visible. On October 10, Lord LINDSAY noted that "since the last measures a decided change is to be seen, as the light is more spread out. The mean brightness is still as before, but is divisible into two lines very close together with a dark gap, and then another very faint line." Measurements of the three lines were made with the following results :—

* 'COPERNICUS,' vol. 2, p. 111.

$$499{\cdot}5 \pm 1{\cdot}1$$
$$492{\cdot}2 \pm 1{\cdot}3$$
$$491{\cdot}8 \pm 1{\cdot}0$$

The latter two "were too feeble and too near together to be effectively measured separately." But regarding this, COPELAND remarks that "the faint extension of the spectrum of this star towards the violet measured on October 10, 1877, was seen with so much difficulty that it would be unwise to regard it as in any certain degree indicating the presence of other nebular lines."

On October 25, 1877, VOGEL succeeded in making another observation of the star's spectrum.* He says :—"The spectrum was almost monochromatic; it consisted of one bright line, on both sides of which a very faint continuous spectrum could be seen." This was measured at wave-length 499. This observation was again confirmed on February 18, 1878.

COPELAND remarked,† "Bearing in mind the history of this star from the time of its discovery by SCHMIDT, it would seem certain that we have an instance before us in which a star has changed into a planetary nebula of small angular diameter," and again,‡ "It seems, therefore, not unreasonable to assume that in the case of a planetary nebula, the whole light of which did not equal the light of a 10th magnitude star, the spectrum might be reduced to a single line, and that this line would then be the one of which the wave-length may be taken at 500·4."

Hence we see that on and after September 3, 1877, the only line seen with certainty was the line near 500, which had gradually increased in brightness since the first observation made on December 5, 1876. All the important spectroscopic observations of Nova Cygni are shown in fig. 3. It is evident that the hydrogen lines were seen by all the observers, and notwithstanding the slightly divergent measures, they have all been inserted in their proper places. This also applies to the line near 500. The yellow line has also been taken to be D. There is a little more difficulty with the lines in the blue, as CORNU and LOHSE differ from VOGEL and COPELAND. CORNU measured a blue line as 451; LOHSE's is approximately estimated at 462, while VOGEL measured a line at the mean place 467. COPELAND measured the line as 463·5, but he is evidently of opinion that VOGEL's wave-length is the more correct, on the ground that it agrees with one of the bright bands in the spectra of the bright-line stars in Cygnus. No accurate measures were made of the groups of lines in the green indicated in VOGEL's map, and the positions of these have been estimated by reference to those stated to be near 514, 527, and 508.

SECCHI also made some observations of the spectrum,§ and he was of opinion that

* 'Berlin Akad. Monatsber.,' 1878, p. 302.
† 'Astr. Nachr.,' 2158.
‡ 'COPERNICUS,' vol. 2, p. 113.
§ 'Astr. Nachr.,' 2116.

one of the bright lines coincided with hydrogen, one with magnesium (*b*), and a third with sodium (D). Referring to this, VOGEL says: "In this he is certainly mistaken, for on January 8 the lines in the neighbourhood of the magnesium group were quite faint, and at D there was not a single bright line to be seen. The bright lines which he noticed had the wave-lengths 500 and 580 mm., and were pretty far distant from the sodium and magnesium lines." It will be noticed that SECCHI'S observation agrees to a certain extent with that of CORNU.

Other observations were made by Mr. BACKHOUSE,* but these simply confirm the presence of bright lines.

With regard to the origins of the lines, we have first unquestionably the bright lines of hydrogen. These gradually dimmed as the star diminished in brightness. Again, there was a line near λ 500, apparently coincident with the chief line in the spectra of the nebulæ, which brightened as the other lines faded. I have given evidence in other papers† to show that this probably owes its origin to the magnesium fluting at the same wave-length, which is seen so very brightly when magnesium is burned in air.

The next in order of importance is, perhaps, the line or band in the blue between F and G, which VOGEL at first saw double (470 and 474), and afterwards single, with a mean wave-length of 467. COPELAND described it as a "faint band," and gave its mean position as 463·5. It is more than likely that this was the compound fluting of carbon in the blue, seen at first with two maxima, as in Nova Coronæ and Comet III., 1881, &c., and afterwards with a single maximum at 468. This band agrees in position with the bright band seen in the spectra of bright-line stars (*e.g.*, WOLF and RAYET'S stars in Cygnus, &c.).

VOGEL also refers to this relation. The two maxima first seen, however, were not recognised by VOGEL as being the same as those observed in Nova Coronæ, although he pointed out that the green line 500 was common to the two as well as the hydrogen lines. In Nova Coronæ there were simply the brightest lines which were afterwards seen in Nova Cygni.

Another important line is the one at 579, about which there is no disagreement between COPELAND and VOGEL. This is undoubtedly the same line which is seen in the bright line stars in Cygnus, as pointed out by COPELAND, and I have previously ascribed it to an iron line which is seen brightest in the flame spectrum.‡

One of the lines in the green is probably also an iron line, 527, the next in intensity to the line at 579. This died out in the Nova before the line 579, and this is what should happen, for in the laboratory 579 is seen without 527 in the coolest part of the flame. The three lines or bands near 564, 552, and 546, are quite

* 'Nature,' vol. 15, p. 295.

† 'Roy. Soc. Proc.,' vol. 43, p. 113, and vol. 48, p. 197.

‡ 'Roy. Soc. Proc.,' vol. 44, p. 33.

familiar in cometary spectra. The first two of them are probably the 1st and 3rd members of the citron carbon fluting, the intermediate one being masked, as in COGGIA's comet, on June 13, 1874.* The one at 546 is the fluting due to lead, which has frequently been recorded in cometary spectra.

The two bands shown in VOGEL's map, at wave-lengths 513 and 517, are probably also carbon bands seen in comets. The less refrangible one is the brighter, exactly as it was in COGGIA's comet, on the occasion just referred to.

On December 5, 8, and 14, VOGEL recorded four faint lines between F and the line 500. One of these is doubtless the nebula line 495; the two between this and F are probably identical with two shown in my photograph of the spectrum of the nebula in Orion.† The other line has not been identified.

Another line of considerable interest is that observed by VOGEL and CORNU, near λ 531, *i.e.*, near the corona line. In VOGEL's observations, the line is always associated with the iron lines E and 519, and as great accuracy is not claimed for the measures, it is quite possible that it is simply the third brightest flame line of iron at 5327. In the map it is represented as being fainter than 527, and this is quite consistent with this origin. CORNU represents the line without E or 579, and suggests that it is identical with the corona line.

The line near 635, recorded by three observers, is no doubt the same as that seen in the spectra of the bright line stars of Cygnus. No terrestrial equivalent has yet been found, but a line in this position is seen in the spectrum of the Limerick meteorite.

It is thus seen that practically all the lines and bands in Nova Cygni can be explained by reference to laboratory work.

It is extremely interesting to attempt to build up the spectrum on any given date by integrating the spectra of comets and nebulæ, or nebulæ and bright-line stars, which we have reason to believe to be swarms of meteorites. Some of these integrations are shown in the diagram (figs. 5, 6, and 7). As in Novæ we have to deal with collisions of swarms of meteorites of different densities, in such integrations it is necessary to take swarms of different degrees of condensation.

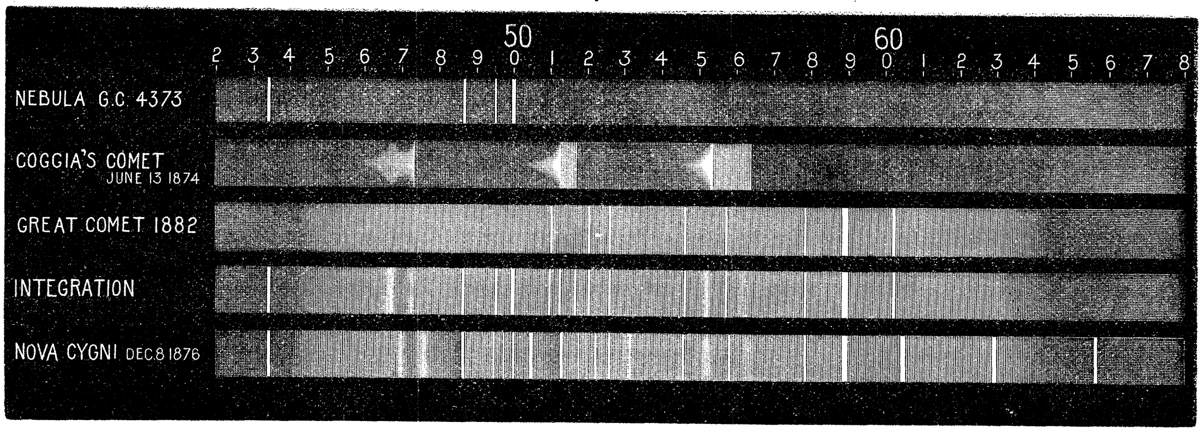
The first integration shown (fig. 5) is for the spectrum of December 8, as observed by VOGEL. In this case the spectrum is reproduced almost line for line by adding together the spectra of a nebula, COGGIA's Comet (June 13, 1874), and Great Comet of 1882 at perihelion (brightest lines only). The only lines of importance which are in the Nova and not in the integration are C and a line near 635, and we know that these are associated with the spectra of meteor-swarms; C occurs in γ Cassiopeiæ and β Lyræ, and the line at 635 occurs in the bright-line stars in Cygnus. This integration strengthens the view that Nova Cygni was produced by the collision of swarms of different densities. In such a case there would first be the collisions

* 'Roy. Soc. Proc.,' vol. 45, p. 175.

† 'Roy Soc. Proc.,' vol. 48, p. 200.

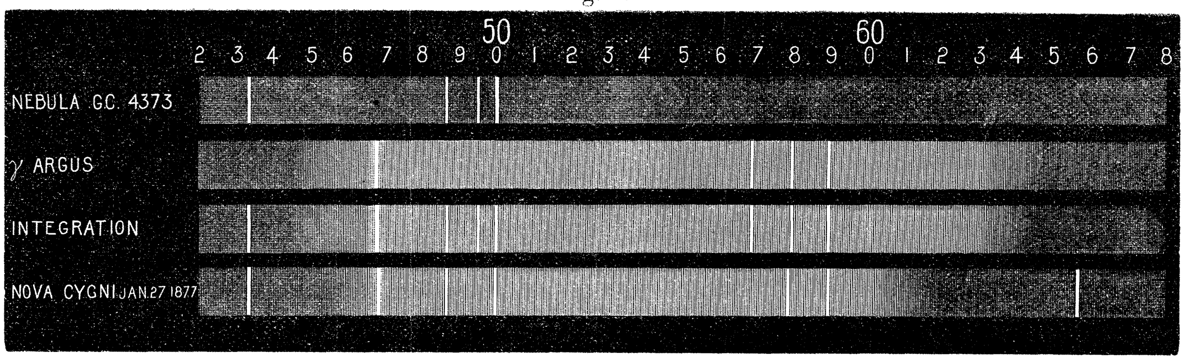
between the two sets of outliers, then the denser part of the smaller swarm would enter the outliers of the larger, and finally the densest parts of both swarms would

Fig. 5.



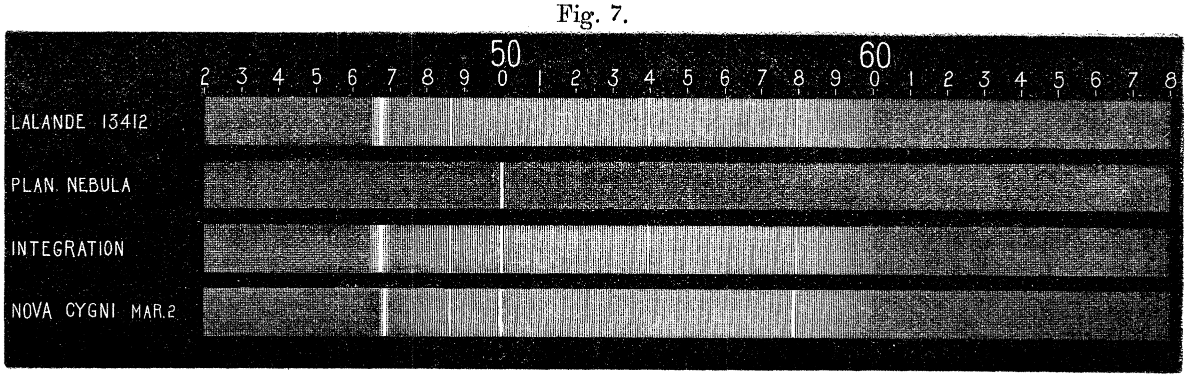
Integration of the spectra of comets and nebula, compared with that of Nova Cygni.

Fig. 6.



Integration of the spectra of nebula 4373 and γ Argûs compared with that of Nova Cygni.

Fig. 7.



Integration of the spectra of a planetary nebula and LALANDE 13,412, compared with that of Nova Cygni.

come together; so that, in this way, the resulting temperature effects may be very complicated.

The spectrum of the Nova on a later date, January 27, 1877, is considerably simpler than that of December 8, and may be almost perfectly reproduced by integrating the spectrum of a planetary nebula and that of γ Argûs (fig. 6). All the lines in the Nova on this date are shown in the integration, with the exception of the C line. The integration, however, in this case shows the lines at 495 and 568, which were not recorded in the Nova; but their absence was probably only due to difficulties of observation. The line at 495 is excessively faint in some nebulæ.

The spectrum of the Nova on March 2 was still simpler than on former days, and can be fairly reproduced by adding together the spectrum of the bright-line star, LALANDE 13,412, and that of a planetary nebula which shows only the chief line of the nebulæ. This is shown in fig. 7. The temperature in this case is obviously very much lower. We get only the lowest temperature line of iron at 579, of magnesium 500, the F line of hydrogen, and a slight indication of carbon. The absence from the Nova of the line near 540 is probably also due to difficulties of observation.

It will thus be seen that the complete discussion of Nova Cygni generally bears out the statement I ventured to make after the preliminary inquiry in November, 1887, viz.: "This star passed through all the changes of temperature represented by stars with bright lines, comets, and nebulæ."

The complete series of observations of the magnitude of this star was as follows:—*

Date.	Magnitude.	Date.	Magnitude.
1876.		1876.	
November 24	3	December 12	6·7
,, 25	3·1	,, 13	6·8
,, 26	3·1	,, 14	6·9
,, 27	3·2	,, 15	7·0
,, 28	3·8	1877.	
,, 29	4·7	January 1	7·2
,, 30	5	,, 2	7·4
December 1	5·2	,, 16	$>7·6$
,, 2	5·4	,, 18	$>7·6$
,, 3	5·6	February 2	7·6
,, 4	5·8	March 2	8·5
,, 5	5·9	,, 10	8·3
,, 7	6·3	October 25	<10
,, 8	6·5	1878.	
,, 9	6·6	February 13	<11
,, 11	6·7	,, 18	11·5

Nova Andromedæ, 1885.

The spectrum of Nova Andromedæ was first examined by Dr. COPELAND on September 1, 1885, when it was noted† "the spectrum was continuous from end to end, and only on close examination could slight condensations, indicative of bright lines,

* 'Astr. Nachr.,' vol. 89, 1877, p. 42. 'Berlin Akad. Monatsber.,' 1877.

† 'Monthly Notices, R. A. S.,' vol. 47, p. 50.

be detected. The spectrum was not considered to differ strikingly from that of the nebula." At this time the star was "yellowish" in colour, on September 3 it was "full yellow." A close spectroscopic examination, however, was not possible until September 10, when Dr. COPELAND wrote:—"With the unmagnified dispersion of a direct-vision Vogel spectroscope the spectrum extended from W.L. 670 mmm. to 453 mmm., or, from between B and C to half-way between F and G. When the spectrum was sufficiently narrow all the colours were visible, with a suspicion of brighter points in the line. An attempt was made to measure these with the Grubb spectroscope and a flint prism of only 40° refracting angle. The instrumental change cut down the spectrum to the limits of 600 mmm. and 456 mmm., with a maximum at 544·41 mmm., and a suspicion of a bright line, but hardly more at 482·2 mmm. With the same apparatus the spectrum appeared *quite continuous* on September 11, but again showed traces of bands on the 13th, and was slightly banded on the 15th. Traces of a condensation of light were seen at W.L. 471·6 mmm. on September 20." Using a special acute prism of only 15° angle, it was noted: "Only traces of two brighter points towards the yellow end of the spectrum could be made out on September 30, the rest of the spectrum appearing absolutely continuous." On October 1, these two lines and another fainter one were measured, the following being the wave-lengths found, and their mean values:—

Band 1.	Band 2.	Band 3.
557·1 541·8 541·5	510·1 519·5 512·4	493·1 489·9 484·5
Mean wave-length 546·8	514·0	489·2
Red end of spectrum, 575·8. Violet end of spectrum, 467·6.		

Dr. COPELAND thought that some of the discordances of the above measures were due to the indeterminateness of the objects measured, and noted that "making due allowance for this uncertainty, it seems probable that the three 'bright' bands of wave-lengths 546·8, 514·0, and 489·2, are identical with the three brightest bands afterwards measured with the same apparatus in Mr. GORE'S *Nova Orionis*, of which the brightest parts were at wave-lengths 542·8, 516·2, and 494·4.* The trace of a condensation of light at W.L. 471·6, seen on September 20, agrees well with the bright line in Nova Orionis at W.L. 472·2; while the maximum of light in Nova Andromedæ at 544·4, on September 10, is closely in accord with that for the star in Orion at 542·8· The only really discordant item is the point laid down at 482·2 on September 10, which does not correspond to any known bright band in the spectra of variable stars; it was, however, entered in the note book . . . as 'a suspicion

* 'Monthly Notices, R. A. S.,' vol. 46, p. 110.

of a bright line, but hardly more.' But if it does roughly represent the position of a 'bright' line actually visible in the spectroscope, one would feel inclined to regard it as a trace of the F line. On October 2, the spectrum presented the same appearance as on the preceding day. On October 19, it could be still noted as continuous, but not uniform, with the Vogel spectroscope.

"Although the foregoing results differ widely from those obtained at Greenwich and also at Yale College" [which will be given subsequently], "as regards the three chief lines the observer cannot doubt as to their general correctness. . . . . Besides, in the case of an object losing so rapidly its power of emitting light, it is quite possible that the spectrum may have slightly varied from day to day.

"In conclusion, it seems worthy of remark that the spectrum described above is the same as that given by any ordinary hydrocarbon flame, burning so feebly that the spectrum of the blue base of the flame is just beginning to show through the continuous spectrum afforded by the white part of the flame."

On September 1, Professor VOGEL observed the spectrum and noted that the red and yellow were bright and the green faint. He also found dark lines or bands, one between the yellow and green, and another between F and G.*

Dr. HUGGINS communicated his observations of Nova Andromedæ to the 'Observatory for October, 1885. They are as follows :—"The star was observed here first on the night of the 3rd instant. It presented the appearance of an orange-coloured star of from the 8th to the 9th magnitude. With a spectroscope of low dispersive power, a continuous spectrum was seen from about C in the red to a little beyond F. There was an apparent condensation of light from about D to *b*, which might be due to bright lines in that part of the spectrum. This supposition was strengthened by the employment of a more powerful spectroscope, but I was not able to be certain on this point.

"On the night of the 9th instant, the star, which was then distinctly on one side of the principal point of condensation in the nebula, appeared to me to have a less decided orange tint. It presented a similar appearance in the spectroscope, with the exception that the light was less strong about D. I was, so far, confirmed in my suspicion of bright lines, that I have little doubt that from three to five bright lines were present between D and *b*."

On September 4 Mr. MAUNDER noted that† "the star gave a perfectly continuous

* "Die Beobachtungen am 1. und 2. September über den Stern in Nebel ergeben, dass derselbe auch bei stärkerer Vergrösserung (550 f.) vollkommen sternartig bleibt, und dass das Spectrum continuirlich ist. Die Intensitäten der Farben im Spectrum scheinen etwas abweichend von den gewöhnlichen Sternspectren zu sein, indem Roth und Gelb besonders stark hervortreten, Grün aber verhältnissmässig schwach ist. An der Grenze des Gelb und Grün habe ich eine dunkle verwaschene Bande vermuthet, eine zweite ebensolche im Blau zwischen F und G. Im Fall der Stern noch heller werden sollte, denke ich Sicherheit über weiteres Detail, welches ich im Spectrum vermuthete, zu erlangen. Ich bemerke noch dass der Andromeda-Nebel continuirliches Spectrum giebt und dass der Kern des Nebels h. 51 ein Spectrum zeigt, was mit dem des neu entstandenen Sterns in h. 50 übereinzustimmen scheint." ('Astr. Nachr.,' 2681.)

† 'Monthly Notices, R. A. S.,' vol. 46, p. 19.

spectrum, in which no lines, either bright or dark, could be detected. The red, orange, and violet were very faint, or altogether wanting, the spectrum being traceable from about D to F, but being scarcely discernible beyond those limits. The spectrum of the star resembled that of the nebula precisely, except, of course, that it was brighter, and, probably in consequence of this greater brightness, was traceable a little further in both directions.

"On the evening of September 11 the single prism spectroscope was employed, and the lower dispersion of this instrument proved more suitable for the examination of so difficult an object. The spectrum of the star was now traced from about λ 6600 to λ 4300; it was very faint in the red and range, and began to brighten at a definite point, either D or close to it. Then followed a space relatively very bright, the centre of which was not far from E, but the brightest part of which was further towards the red, at a point for which two readings were obtained, viz.:—λ 5457 and λ 5508, mean λ 5482, and where at times the brightening appeared so definite as to suggest the presence of a bright line. The same general region was also much the brightest in the region of the nebula. The spectrum of the star declined rapidly in brightness beyond F, practically it might be considered as confined between the two lines, D and F, the outer portions of the spectrum were so much fainter than the central district. From time to time bright lines were suspected in this district, the brightest being the line already mentioned, a second being measured as at λ 5327. The region of the *b* lines was specially examined, and also the neighbourhoods of both D and F, but no bright lines were seen in either locality.

"The spectrum of the star was examined with a small prism held behind the eye-piece, on September 15, and the presence of the two bright lines was again suspected And again, on September 30, they were more satisfactorily observed, although the star had then lost much of its brightness, and its spectrum was but little brighter than that of the nucleus of the nebula. A third line was also suspected about as far beyond the magnesium line, λ 5527, towards the red, as the brightest of the three bright lines, viz., that at λ 5482, was towards the blue. This would give its position as λ 5575. It could not be decided whether the lines were brighter than on September 11. They were recognised more easily than on that occasion; but, on the one hand, it was known where they should be looked for, and, on the other, the instrument now employed (the half prism spectroscope in the reversed position) was the same as that used on September 4 when no trace of a bright line could be perceived. It was believed that the brightest line, that of λ 5482, could be traced over or near the nucleus of the nebula, but with so feeble a spectrum it was most difficult to make perfectly sure. The slit also was narrow, and it was found most difficult to keep either star or nebula upon it, their spectra being so faint that they were continually being lost."

The following are some measures of the limits of visibility of the spectra of two stars, the Nova and the nebula, made by Mr. MAUNDER on September 11:—

	Limit towards the red.	Limit towards the blue.
	mm.	mm.
Arg. Z + 38° No. 90 . . .	7380	3948
Arg. Z + 38° No. 88 . . .	6608	4095
Nova	6615	4319
Nebula	6196	4363

Mr. MAUNDER remarked, with respect to these measures, "The spectrum of the Nova was traceable a little further in both directions than that of the nebula. Towards the violet this seemed entirely due to its greater brightness, but towards the red the difference was greater than could fairly be explained upon this ground. The spectrum of the Nova seemed slightly brighter than that of No. 88 in the central district from D to F, but was decidedly feebler in the red and violet regions. The Nova was estimated as being three-tenths of a magnitude fainter than No. 88."

KONKOLY, writing on September 5, noted that he observed the spectrum of Nova Andromedæ on the previous day.* In his words:—"Yesterday, when I examined the star, it seemed of a reddish-yellow colour and very faint. I estimated its diameter at, at least, two seconds; it appeared as a nebulous star. Its spectrum was unexpectedly faint, so that it was impossible to use a cylindrical lens. The edges of the spectrum seemed to be enveloped in a coloured mist. It gives the impression of bright fields on a dark ground, and in the red, yellow, green, and blue a broad band is seen. If this be the case, these broad bright regions would correspond to the hydrogen lines C, F, as well as D_3, and at an enormously high pressure. A similar broad field is also seen in the green, which certainly cannot belong to the group named. I should be inclined to class the spectrum with Type III*b*., and Professor RITTER coincides in this view.

"It must not be overlooked that the violet part is absent in the spectrum; and shortly behind the region of F the spectrum is just as if cut off. This observation was confirmed by Dr. v. KOVESLIGETBY."

Mr. O. T. SHERMAN, of Yale College Observatory, observed the spectrum of the Nova on the early morning of September 5, and noted†: "On the whitish-blue stripe forming the continuous spectrum were discerned one bright line crossing the spectrum, and further towards the red two bright knots of light. They were not very much brighter than the surrounding glare, but were evident. They remained even when the larger dispersion was employed." The positions of the lines were determined by micrometric measurements relative to bright lines in γ Cassiopeiæ and β Lyræ. Curves were plotted connecting the readings of the micrometer and wave-lengths; the four lines H_α, D_3, H_β, and H_δ being used for a foundation. The following are the wave-lengths thus found for two of the lines in the Nova, as estimated from each of the respective curves:—

* 'Astr. Nachr.,' 2681.

† 'Astr. Nachr.,' 2691.

From γ Cassiopeiæ.	From β Lyræ.	Mean.
536·0	527·0	531·5
564·0	551·0	557·5

The third line was identified as H_β, and Mr. SHERMAN thought that from its image it seemed to be due to the light of the whole nebula. The other two lines appeared to be due to the light of the Nova. All the bright lines in the Nova spectrum were noted by Mr. SHERMAN as occurring in γ Cassiopeiæ and β Lyræ.

It is also remarked that similar observations were made on September 7, 9, and 11, and that the lines were seen on September 16 and 21, but not measured.

Some observations of the Nova were made by Dr. LOHSE with the 15·5 inch Cooke refractor, at Mr. WIGGLESWORTH's Observatory.*

On September 3 it was noted "The spectrum is continuous, no lines could be distinguished in it with the Browning and Maclean spectroscopes. The bright C line was very well seen in γ Cassiopeiæ."

On September 9 Dr. LOHSE recorded: "The spectrum is still continuous, but the part from F to about midway between F and G is fainter than in the spectra of neighbouring stars. In consequence of that, the spectrum near G appears comparatively brighter than the corresponding part of the spectrum of B.—W.$_2$, $0^h.953$, which has about the same brightness. The position of the fainter part in the spectrum depends on estimation, there being no means for measuring the wave-length."

Observations made on September 12, led Dr. LOHSE to write: "The spectrum is continuous and as long as D.M. + 40°·145, if not longer. Much attention was paid to the red end of the spectrum, and repeated comparisons of the two spectra convinced me that this part of the spectrum is quite as much developed in the new star as in D.M. + 40° 145. The observations were made with a Maclean prism, held in front of the eyepiece, and are only estimations."

The late Rev. S. J. PERRY recorded:† "The Nova in Andromeda has been observed at Stonyhurst on every favourable occasion from September 13 to November 8. On September 13, the spectrum was found to be continuous, but the red end was absent, and there was a decided maximum in the green. A bright band in the green was suspected, but not clearly seen. The spectroscope was carefully focussed on the lines in the spectrum of β Andromedæ, which were well seen, before being turned on the nebula of Andromeda. On October 9 the spectrum was still brightest in the green."

The following table brings these observations together in a convenient way for reference. As far as I know, every observation which was made is included.

* 'Monthly Notices, R. A. S.,' vol. 46, p. 299.

† 'Monthly Notices, R. A. S.,' vol. 46, p. 22.

Date.	Observer.									Remarks.
1885. Sept. 1	COPELAND	..	..	..	..	..	..	..	..	"Slight condensations observed in spectrum."
„ 2	VOGEL	..	..	..	..	..	..	..	..	Red and yellow bright; green faint.
„ 3 }	HUGGINS	..	..	..	..	..	..	..	..	Bright lines suspected.
„ 3 }	LOHSE	..	..	..	..	..	..	..	..	Continuous spectrum.
„ 4 }	KONKOLY	..	F ?	..	..	..	..	D_3 ?	C ?	
„ 4 }	MAUNDER	..	..	..	..	..	..	..	..	"Perfectly continuous."
„ 5	SHERMAN	..	486	..	527–536	..	551–564	..	..	Wave-lengths may be anything between those stated.
„ 7	„	..	486	..	527–536	..	551–564	..	..	
„ 9 }	„	..	486	..	527–536	..	551–564	..	..	
„ 9 }	LOHSE	?	..	..	..	..	..	..	..	"Faint part midway between."
„ 9 }	HUGGINS		..	..	..	..	..	..	..	Bright lines between D and *b*.
„ 10	COPELAND	..	482	..	..	544	..	..	..	Light less strong about D.
„ 11 }	„	..	..	..	..	..	..	..	..	"Quite continuous."
„ 11 }	SHERMAN	..	486	..	527–536	..	551–564	..	..	Spectrum sharply terminated about D.
„ 11 }	MAUNDER	..	..	..	5327	548	..	?	..	
„ 12	LOHSE	..	..	..	..	..	..	..	..	Continuous.
„ 13	PERRY	..	..	..	..	..	..	..	..	"A maximum in the green."
„ 15	MAUNDER	..	..	..	5327	548	..	..	..	
„ 16	SHERMAN	..	486	..	527–536	..	551–564	..	..	
„ 20	COPELAND	471·6	..	..	..	..	..	..	..	
„ 21	SHERMAN	..	486	..	527–536	..	551–564	..	..	
„ 30 }	COPELAND	..	..	517	..	546	..	..	..	
„ 30 }	MAUNDER	..	..	..	5327	546	558	..	..	
Oct. 1	COPELAND	..	489	517	..	546	..	..	..	
„ 2	„	..	489	517	..	546	..	..	..	
„ 9	PERRY	..	..	..	..	..	..	..	..	"Brightest in the green."
„ 19	COPELAND	..	..	..	..	..	..	..	..	"Continuous, but not uniform."
Suggested origins		C 468–474	H 486 (F)	C 517	Fe 527	Pb 546	Mn 558			

From the foregoing it will be evident that the observations were extremely difficult throughout, owing partly to the dimness of the star and partly to the character of the spectrum. It must also be pointed out that the spectrum observed was the integrated effect of the spectrum of the Nova and the spectrum of the nebula itself. Even the observation of the spectrum of the nebula is one of considerable difficulty, especially when the sky is at all hazy. It then appears simply as a faint continuous band of light, but when the sky is clear it is seen to have at least three maxima. It is evident from the observations of the Nova, that on some occasions the bands in the spectrum of the nebula were observed in addition to those special to the Nova, whilst on others they were not. This appears to have been especially the case in the later observations when the Nova had become dim, and this is, of course, what would be expected. I referred to the spectrum of the nebula and the connection of the Nova with it in a paper which I communicated to the Society in November, 1888.*

I then wrote:—"We have seen that some planetary nebulæ give the same spectrum as a comet at aphelion. It appeared that if the Nebula of Andromeda were further advanced than a planetary nebula in condensation, it should give a spectrum approximating to one of the more advanced cometary stages which have been already discussed.

"The spectrum of this nebula has hitherto been regarded as a perfectly continuous one, but the observations referred to show that there are some parts brighter than others. The spectrum is almost entirely wanting in red and yellow light.

"In the green there are two maxima, the brightest of which is at wave-length 517 as near as could be determined with the wide slit which it was necessary to employ, the other maximum is near 546. One of the observers, Mr. FOWLER, made six independent measures of the maxima on November 20, and got very nearly the same result each time, comparison being made with the spectrum of a Bunsen, and the spectrum of chloride of lead at the temperature of the Bunsen. The measurements were repeated on November 27 with the same result, and on this occasion they were confirmed by another observer, Mr. COPPEN. Another brightness near 474, as determined by comparison with the Bunsen burner, was also suspected, but it was not so easy to measure as the others.

"My suggestion as to the origin of this spectrum is that it is the integration of very slight continuous spectrum, carbon fluting radiation, and the absorption of manganese (558) and lead (546). The citron band of carbon masks, and is masked, by the manganese fluting, and the absorption fluting of lead causes, by contrast, the apparent brightness at 546. The brightest maximum is no doubt the brightest fluting of carbon at 517, and the one in the blue, which was suspected, is probably the blue carbon group 468–474.

"If these observations are confirmed, this nebula is at present at the same stage of condensation as Comet I., 1868, on April 29 (P. P., April 20), which must be regarded

* 'Roy. Soc. Proc.,' vol. 45, p. 215.

as a pretty advanced cometary stage, seeing that it was observed so near perihelion and that the perihelion distance was small."

"The discussion of the observations of Nova Andromedæ, which is not yet completed, shows that there were bright lines in exactly the same positions as the brightnesses which have now been determined in the nucleus of the nebula. The appearance of the Nova was, therefore, probably due to increased temperature, due to collisions taking place between the sparser outliers of the swarm composing the nebula and an external swarm which came in contact with them. The view of the Nova's connection with the nebula is, therefore, greatly strengthened by this inquiry."

These observations have since been confirmed by Mr. TAYLOR,* who observed two brightnesses at 517·4 and 547·3, and suspected one in the blue.

The only lines seen in the Nova which are not seen in the nebula, are F, 531, and 558, with, perhaps, D_3 and C. The spectrum of the nebula shows Mn 558 and Pb 546 absorption, masking the carbon at 564 and making it appear at 546. The Nova spectrum added manganese radiation 558. The line near 530 I have taken as E (527), the lower temperature line of iron at 579 not being visible on account of the greater brightness of the continuous spectrum in that region. The hydrogen lines C and F were probably due to collisions of the outliers of the two swarms. Mr. SHERMAN † recorded F as a line in the nebula, whilst Mr. MAUNDER noted that the line at 548 could be traced over or near the nucleus of the nebula, thus, to a certain extent, confirming the Kensington observations. There is also evidence in the observations to show that the continuous spectrum fluctuated in relative brightness during the visibility of the Nova. The effect of a brightening of the continuous spectrum would be to mask the faint lines in the green or yellow, whilst affecting but little any that might occur in the blue. LOHSE's observation of a "faint part, midway between F and G," in the absence of other lines, is a case in point. It is not unlikely that this was really the blue carbon band which is seen in the nebula itself, although its position was only roughly estimated.

Again, on September 20, Dr. COPELAND observed traces of a condensation of light at wave-length 471·6, and this also was probably the blue carbon band of the nebula, other lines being masked by the brighter continuous spectrum. On other occasions, not even the faint blue band was seen, the spectrum being recorded as quite continuous.

As the brighter continuous spectrum due to the Nova gradually dimmed, the bands of the nebula in the green became more prominent.

It is thus seen that although there does not appear to have been a regular sequence of events in the spectrum of Nova Andromedæ, as far as the actual observations go, it is probably due to difficulties of observation, and to the fact that the spectrum of the Nova was superposed upon that of the nebula. Local atmospheric conditions also had a marked effect upon the observations. Thus, the spectrum

* 'Monthly Notices, R. A. S.,' vol. 49, p. 126.

† 'Ast. Nachr.,' No. 2691.

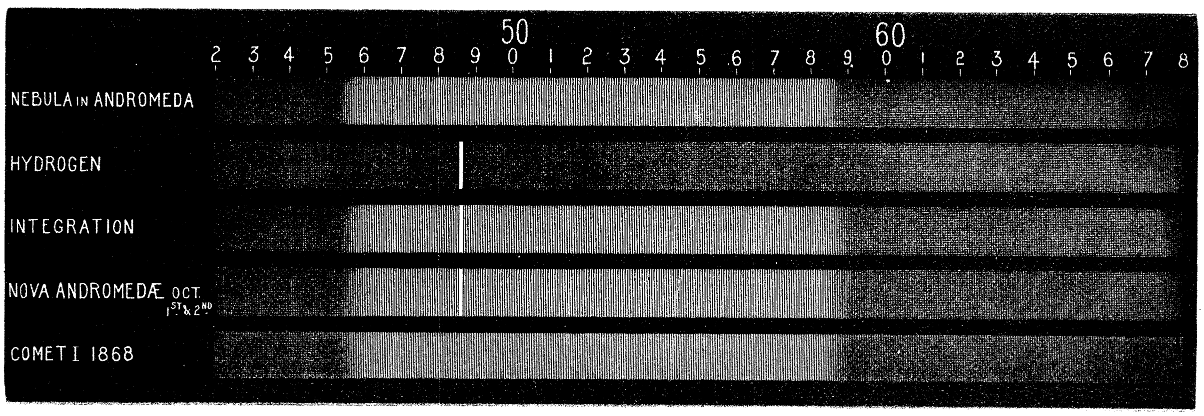
was observed on September 11, by COPELAND, SHERMAN, and MAUNDER; COPELAND recorded a "quite continuous" spectrum, whilst SHERMAN and MAUNDER agreed only with regard to one line.

The apparent variations from day to day are, therefore, not all real, and it is hopeless to attempt to explain them all by reference to the effects of a gradual fall of temperature. The star only diminished about two magnitudes during the period in which spectroscopic observations were made, and hence the change of temperature would not be so great as in Nova Cygni, and consequently the variations of spectrum would not be so evident.

The differences of spectra have also been examined with reference to a possible periodicity of some of the lines, but it has not been found possible to explain the variations in this way.

No lines or bands, however, were on any occasion recorded in the spectrum, with which we are not familiar in other bodies, which there is evidence to show are meteoritic swarms.

Fig. 8.



Integration of spectra of the nebula in Andromeda, and of hydrogen, compared with that of Nova Andromedæ.

The line at λ 546, which was seen in the spectrum of the Nova, was undoubtedly the maximum of light, probably due to lead, which is seen in the nebula itself. This is also the probable explanation of the other lines near λ 517 and λ 473, the latter being only observed on one occasion. The additional lines due to the collision, which produced the Nova, were, therefore, F, 5327, and 558, if we neglect KONKOLY's doubtful observation of C and D_3. The appearance of the hydrogen line F is exactly what would be expected from what we know of its appearance in such stars as Mira, when, by additional collisions due to the periastron passage of a revolving swarm, the star reaches a maximum. The line near λ 558, seen by MAUNDER and SHERMAN, was in all probability due to the brightest manganese fluting at the same wave-length, which is very frequently recorded in cometary and other spectra. This, and the line 5327, which was most likely the iron line E (λ 5268) were probably produced by local collisions in the denser parts of the swarm.

Fig. 8 will show how the spectrum of the Nova, as seen by COPELAND, on October 1 and October 2, can be reproduced by adding the spectrum of hydrogen to that of the Andromeda nebula. The third band of the nebula was not seen, but this is always most difficult to observe. At this time, then, the only line special to the Nova was F, and this, it will be remembered, was seen last in Nova Coronæ.

The spectrum of Comet I., 1868, which differed but slightly from that of the nebula in Andromeda, is added for completeness. In the comet the bright flutings were more prominent than in the nebula, because the continuous spectrum was relatively not so bright.

The star was first seen on August 19 at Belfast by Mr. WARD, and on the 27th, by Mr. LUDOVIC GULLY of Rouen. The first public announcement of the change was made by Dr. HARTWIG, who observed it on August 31. The following are the observed changes in magnitude :—

Date.	Magnitude.	Date.	Magnitude.
1885.		1885.	
August 19 . .	9·0	October 4 . .	10·39
September 1 . .	8·47	,, 5 . .	10·47
,, 3 . .	8·55	,, 6 . .	10·47
,, 5 . .	8·63	,, 7 . .	10·47
,, 9 . .	8·71	,, 19 . .	10·91
,, 10 . .	8·71	November 4 . .	10·95
,, 11 . .	8·85	,, 5 . .	10·95
,, 12 . .	8·97	,, 7 . .	10·95
,, 13 . .	8·97	,, 30 . .	11·9
,, 15 . .	9·17	December 2 . .	12·1
,, 17 . .	9·49	,, 29 . .	13·0
,, 19 . .	9·41	1886.	
,, 29 . .	9·75	January 2 . .	13·5
,, 30 . .	9·83	February 2 . .	Not a trace of the Nova with 15 inches aperture.
October 2 . .	9·91		

VI. THE SEQUENCE OF PHENOMENA IN THE SPECTRA OF NOVÆ.

Sequence of Spectra.

If the appearance of a new star be due to the collision of two meteor swarms as I have suggested, it is obvious that the spectroscopic changes should follow the same order as those observed in the spectrum of a comet during its passage from perihelion to aphelion, when differences of observing conditions, and the relative physical conditions of the two swarms which produce a Nova, are duly allowed for.

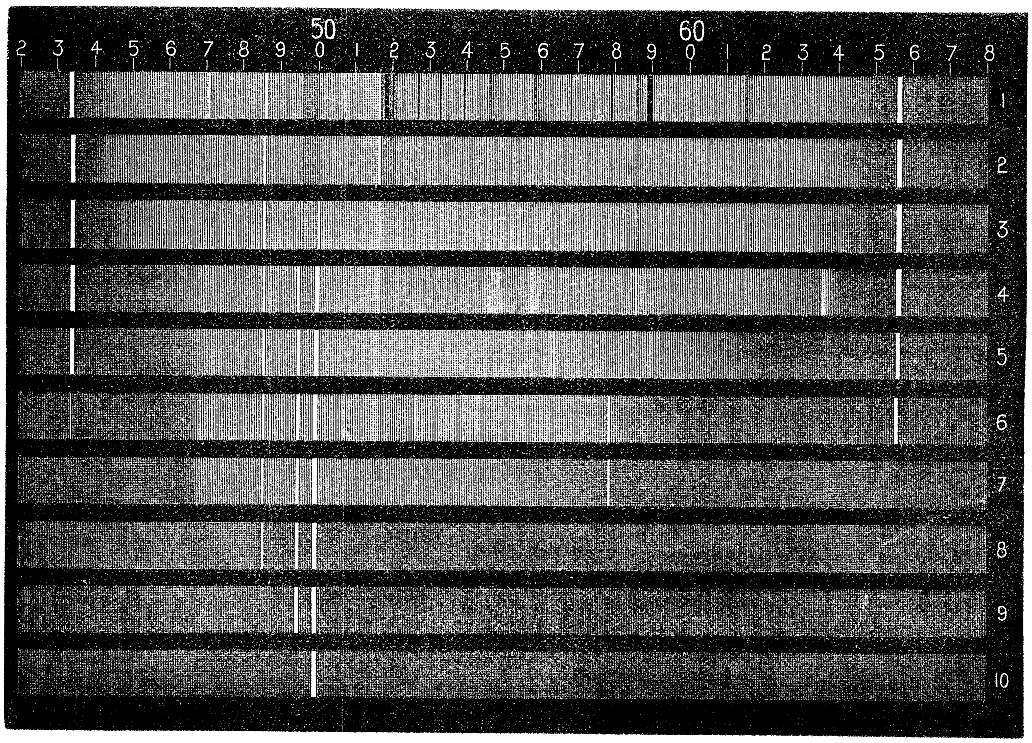
The following map (fig. 9) shows the theoretical sequence from this point of view commencing with one swarm sufficiently sparse to give only the bright lines of hydrogen and flutings of carbon, and the other sufficiently dense to give dark D and *b* and the flutings of lead, manganese, and iron, with bright carbon flutings. The first horizon accordingly shows the integration of these two spectra, and subsequent ones the effects of cooling of the mixed swarm.

None of the four Novæ, which have been spectroscopically examined, have shown the complete sequence of changes indicated in the map, but Nova Cygni passed through most of them.

The first horizon gives the typical spectrum of the light due to the collision of two swarms of meteorites; it consists of metallic absorption lines and flutings as in *α* Orionis, together with hydrogen and hot carbon radiation.

The spectrum of Nova Coronæ on May 16, was very similar to this.

Fig. 9.



Sequence of spectra in Novæ.

As the Nova decreases in temperature, and, therefore, in light, the line absorption disappears and the metallic fluting absorption decreases in intensity. Carbon radiation, and the hydrogen lines, C, F, and G, remain about the same as before (2).

The next stage (3) brings us to a condition represented by a swarm of Species 3, Group II.* The manganese and lead absorption at 558 and 546 respectively, are now overpowered by the carbon radiation at 564, whilst the absorption of the second manganese fluting at 586 is still apparent. The hydrogen lines, C, F, and G, remain almost as before.

On the following horizon (4) is represented the radiation of lines and flutings. The manganese and lead radiation are visible. The brightest iron and magnesium

* Bakerian Lecture, 1888, p. 66.

lines are seen; also sodium, D, and the line at 495, whilst the brightest edge of the magnesium fluting at 500 is just visible. This was a condition observed by VOGEL in Nova Cygni, on December 8, 1876. It was also observed in the Great Comet of 1882, when near perihelion, and is a condition apparently very similar to that of γ Cassiopeiæ.

The condition following this (5) is that in which lead and manganese radiation have disappeared; the three carbon flutings are well seen, C, F, and G are rather fainter, but the fluting at 500 appears brighter. The 495 line and the iron line 579 are still seen, the other iron lines in the green being masked by the brightness of the continuous spectrum. This condition was approached in Nova Cygni on February 2.

On the following horizon (6) the 564 carbon fluting is not visible, and the 517 fluting appears almost as a line. The iron lines, 579 and E, are now visible in consequence of the fading of the continuous spectrum. The hydrogen lines are still visible, whilst D has disappeared. The two magnesium flutings, 5210 and 500, are each represented, the latter being the brighter. This stage in the sequence was observed in Nova Cygni on February 2, and the brightest of the lines in Nova Coronæ, May 19. All the lines have been recorded in the spectrum of the nebula in Orion.

Both the carbon flutings, 517 and 564, now disappear (7), having become so pale that they are masked by the continuous spectrum, whilst the 468 maximum of the carbon fluting is visible, because the continuous spectrum does not reach it. F is the only remaining hydrogen line, and 579 the remaining iron line, this being the line visible at the lowest temperature. 495 is rather fainter, whilst 500 has increased in brightness. This stage was observed in Nova Cygni on March 2, 1877. The 474 carbon is the next to disappear, and three lines only are left:—F, 495, and 500 (8). The nebula G. C. 4373 and many others give this spectrum. No observations of Nova Cygni were made between March and September, 1877, and it is between these dates that this stage would have occurred.

With regard to horizon (9), the nebula G. C. 2343 and many others give a spectrum consisting of two lines, 495 and 500, and Lord LINDSAY observed in Nova Cygni, on October 10, 1877, a line at 492 (as well as the line at 500), which was most probably the nebula line at 495.

The last stage in the sequence is when the 500 fluting remains alone (10). This was observed in Nova Cygni by VOGEL and by COPELAND; it is the only line in the G. C. 4403, and, as I have shown in the appendix to the Bakerian Lecture, it is the characteristic line of comets when at a great distance from the Sun, and was observed by Dr. HUGGINS in 1866 and 1867.

It should be remarked that this is only one hypothetical case of a Nova, and that there may be considerable variations from it, according to the initial conditions of the two swarms which produce the Nova by collisions. Thus, in the case of Nova Andromedæ, one of the swarms already existed as a considerably condensed nebula and the collision with the other swarm only sufficed to bring out a few more lines, including the F line of hydrogen. Here, then, the initial spectrum would be different, and the subsequent changes would not take place in exactly the same order. The integrations which have been given, however, show that it is possible in any of the Novæ which have yet been spectroscopically observed to get a good idea of the states of condensation of the two swarms after the first collision.

It is important to compare this sequence with that which I have already given for comets,* for, though the conditions are different, there will be a certain similarity, since both have to be regarded as meteor swarms. On the first three horizons of the Nova sequence we have mixed radiation and absorption phenomena; this also occurs in comets, though the difference in the brightness of the continuous spectrum does not make it so obvious. On the fourth horizon of the Nova sequence we have carbon, manganese, and lead radiations, which also occur in comets; but, in addition, there are lines of hydrogen and other substances due to the compound character of the swarm. Finally, both Novæ and comets give one line, the chief line of the nebulæ, which is probably due to magnesium. It will be seen that the spectra of Novæ are, in general, more complex than those of comets, which results from the collision of two swarms of different densities.

Variations in Magnitudes.

In each case where the spectra of new stars have been observed the evidence tends to show that the star was hottest at the first observation; the absorption lines giving way to bright lines in Nova Coronæ, the brightest lines fading away one by one in Nova Cygni, and the carbon becoming more manifest in Nova Andromedæ, all go to show a diminution in the temperature of the star after the first observation. Indeed, in only one case, that of Nova Andromedæ, have I been able to find any evidence of a new star increasing in brightness after its discovery. Assuming that the Nova was physically connected with the nebula, this increase of brightness is exactly what would be expected from a consideration of the beautiful photograph obtained by Mr. ROBERTS, which shows that the nebula is really a spiral system. We have only to suppose the incoming swarm to pass from the outside to the inside of one of the rings—a region of gradually increasing density—to give the required explanation. After a time the rotation of the nebula would bring so many more meteorites to the point of disturbance that their motions would predominate and the "Nova" would begin to fade.

It is very probable that a Nova would be overlooked until transcendently bright, and the observations of the magnitudes of Novæ show that such has been the case. It is, however, essential to my theory that the increase in temperature and in luminosity shall be much more sudden than the decrease.

The first observations of Nova Coronæ, which showed the same absorption lines as

* 'Roy. Soc. Proc.,' vol. 45, p. 190.

α Orionis, indicate a comparatively high temperature, and it also was a Nova that flashed out very suddenly. M. COURBEBAISSE and Mr. BAXENDELL* held that the Nova could not have been conspicuous two days before its discovery, and were confident it was not visible three days before. Many other observers support this statement. Hence it is evident that in these cases we are dealing with the collisions of two rather condensed swarms of meteorites, the consequent temperature being high and the increase in light sudden. In Nova Andromedæ, where the increase in luminosity was not so sudden, the temperature was not nearly so high. In this case we had most probably to deal with the collision of two swarms not nearly so condensed as in Nova Coronæ; perhaps a slightly condensed swarm passing through the Andromeda nebula, in which case the increase in temperature would be more gradual and comparatively small. When my paper of November, 1887, was read I was unaware that comets would give evidence of absorption in their spectra, but the more recent work has shown that in comets at or near perihelion the absorption of Mn and Pb have been indicated very frequently. Hence, no difference exists between the spectra of new stars and of comets. I remarked in that paper† that the spectra of stars of Class III*a*. and some "Novæ," notably Nova Orionis, were strikingly similar, and I wrote regarding this fact: "We have then, in these bodies, a spectrum integrating the *radiation* of carbon and the absorption of Mn and Pb vapour, and I have shown that comets give at some time during their revolution, providing the perihelion distance is not too great, the same spectrum"

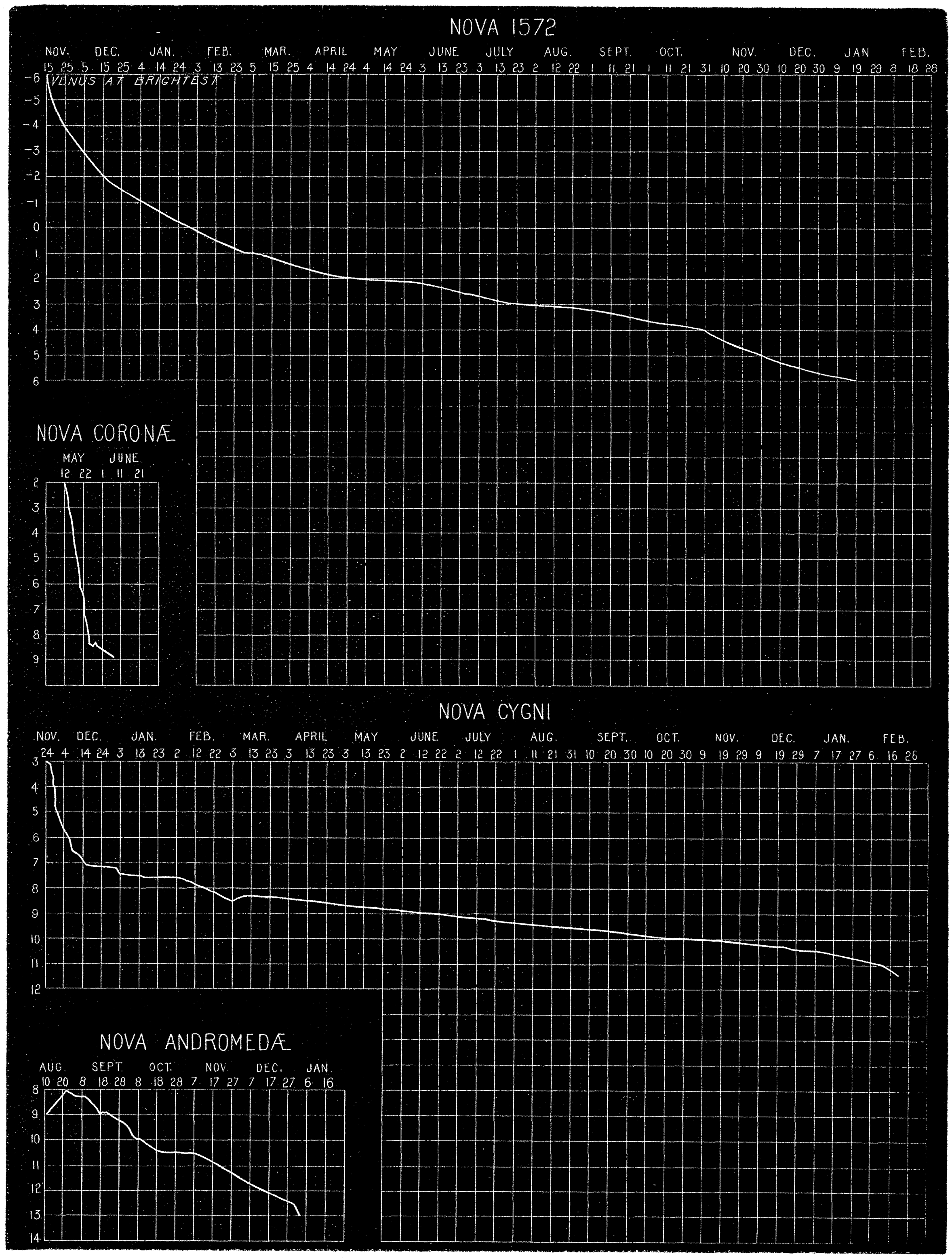
Nova Cygni decreased in magnitude in a very similar manner to TYCHO BRAHE'S Nova, dimming very suddenly at first, and more slowly later on. In three months the Nova fell from the 3rd to the 8th magnitude, and then the fall from 8 to 11 took twelve months. The brightness of this Nova, as well as its long period of visibility, afforded the opportunity for many observations of its spectrum, the result being that the sequence of phenomena, as far as it goes, is much more complete in it than in any other Nova, which brings us to the conclusion that other Novæ would have given a more complete sequence if more spectroscopic observations could have been made.

All the changes in the magnitudes of Novæ which have been recorded, so far I know, are shown in fig. 10.

* 'Monthly Notices, R. A. S.,' vol. 26, p. 293.

† 'Roy. Soc. Proc.,' November, 1887, p. 130.

Fig. 10.



Light curves of Novæ.

VII. Colour Phenomena.

The Changes of Colour in Condensing Swarms.

During the condensation of a nebulous swarm to a star of Group IV. the changes of colour occur in the following order, so far as we know at present :—

Group IV.	Highest Temperature	Bluish-white.
Group III. to Group II.	Intermediate Temperatures	White. Yellowish-white. Yellow. Orange. Reddish-yellow. Yellowish-red. Red. Yellowish-red. Reddish-yellow.
Group I.	Lowest Temperature	Dull white, grey, or pale bluish-green.

I have shown in a former paper* that the reddest stars on the ascending side of the temperature curve fall in the middle species of Group II., as represented in the above table. Hence as the cooler swarms of Group I. are of a dull white, grey, or pale bluish-green, it follows that there must be a gradual increase of redness in passing from Group I. to the middle species of Group II., and a decrease of redness in passing from there to higher points of the temperature curve. It is probable therefore that the succession of colours takes place very nearly in the order stated.

Mixed Colours in Novæ.

It must, however, be remembered that the sudden increase of temperature which determines the appearance of a New Star is of quite a different character to the increase of temperature due to the condensation of a single meteoritic swarm. The phenomena accompanying each would therefore be different.

In the case of New Stars, we have to begin with two meteoritic swarms, possibly in different stages of condensation. If no star or nebula were visible before, the sudden increase of light would be due to the collision of two dark swarms or streams. If one of the swarms engaged already existed as a nebula, the collision of another with it would cause an outburst similar to that of Nova Andromedæ. If one swarm existed as a star, and was therefore rather more condensed, the collision of another swarm with it would produce a higher temperature ; this was the case with Nova Coronæ. But after the disturbance due to the collision had subsided, the tem-

* 'Roy. Soc. Proc.,' vol. 46, p. 418.

perature must begin to fall, as the mixed swarm is not in a condition to keep it up. *Novæ, therefore, run back along the temperature curve,** and their colour changes will in general take place in the opposite order to that followed by a condensing nebulous swarm. Hence the colour of New Stars will be generally of a compound nature, and made up of the luminosity of the pre-existing nebula or star, together with the added light brought about by collisions.

The changes of colour will depend upon the relative amounts of light received from the two sources of luminosity of the Nova. This again may depend either upon the relative volumes occupied by the two swarms or upon their temperatures. If, for instance, the Nova consists of a large sparse swarm combined with a smaller and more condensed one, the light at first would be mainly that of the condensed part, the feeble blue or green light of the sparser swarm being overpowered. With rapid cooling in such a case, the light from the condensation would diminish in greater proportion than that from the larger mass, and the blue colour would then begin to assert itself. If the light from the condensation were reddish, this addition of blue light would tend to produce a purple tint, as in Nova Cygni, or a leaden one as in the star of 1572.

I have compiled the following colour observations, and a compound origin, especially in the case of Nova Coronæ, comes out very strongly :—

The Nova of 173 A.D.

The first recorded observation of colour changes of new stars that I have been able to find is given by BIOT in the 'Connaissance des Temps,' 1846, and is a translation of a Chinese observation made on 10th December, 173 A.D.

"Période Chi-ping 2e. 10e lune jour Kouli-lai. Une étoile extraordinaire parut au milieu des tran-men (α, β, pied oriental du Centaure); elle était grande comme une matte de bambou et présenta *successivement* les cinq couleurs; elle diminua peu-à-peu jusqu'à la 6e lune de l'année suivante (vers juillet), où elle disparut."

I have not, however, been able to discover what colours are here referred to, so that it cannot be said whether the changes are such as occur in condensing swarms of meteorites or not.

Colour Changes in Nova Cassiopeiæ, 1572.

The treatise written by TYCHO BRAHE on the Nova which appeared in 1572, has already been referred to. The Nova was observed to go through regular changes of colour as it diminished in magnitude. These changes are recorded in the introductory part of this paper, and show a close similarity to those observed in other Novæ. At first the star was a dazzling white, then it became yellow, then reddish, and latterly it was hardly definable, but has been described as "leaden-coloured." The most

* 'Roy. Soc. Proc.,' vol. 43, p. 143.

manifest changes in colour took place during the first third of the period of visibility, when the star was rapidly decreasing in brightness.

To sum up then, the changes in Nova Cassiopeiæ may be taken as follows:—

White.
Yellow.
Red.
Leaden-coloured.

It will be seen that this sequence in the early stages only differs from that which takes place in condensing swarms in point of detail, the more minute changes not having been recorded. The leaden colour in the last stage was no doubt due to the blue light from the sparser regions, as I have already pointed out.

Nova Coronæ.

In this star the compounding of colours is manifest.

12th May . .	White, with a bluish look. (BIRMINGHAM, 'Monthly Notices,' vol. 26, p. 310.)
15th May . .	White, with a bluish look. (BAXENDELL, 'Monthly Notices,' vol. 27, p. 5.)
16th May . .	Cream-coloured, *yellow seen through blue film.* ('Monthly Notices,' vol. 27, p. 5.)
19th May . .	Buff-coloured. ('Monthly Notices,' vol. 27, p. 5.)
21st May . .	Leaden, slight orange tinge. ('Monthly Notices,' vol. 27, p. 5.)
22nd May . .	No yellow or red. ('Monthly Notices,' vol. 27, p. 5.)
23rd May . .	Dull grey. ('Monthly Notices,' vol. 27, p. 5.)
24th May . .	Dull white, tinge of orange. ('Monthly Notices,' vol. 27, p. 5.)
25th May . .	Slightly orange-white. ('Monthly Notices,' vol. 27, p. 5.)
26th May . .	Dull orange-white. ('Monthly Notices,' vol. 27, p. 5.)
29th May . .	Dull orange-yellow. ('Monthly Notices,' vol. 27, p. 5.)
2nd June . .	Orange, no longer striking. ('Monthly Notices,' vol. 26, p. 298.)
25th June . .	Orange-yellow. ('Monthly Notices,' vol. 27, p. 5.)
26th June . .	Orange. ('Monthly Notices,' vol. 27, p. 5.)
11th July . .	Dull yellow. ('Monthly Notices,' vol. 27, p. 5.)

The star had a yellowish tint to November 6, 1866. It appears, therefore, that when first visible the colour of this star was compounded of the yellowish-white colour of a swarm in an advanced stage of condensation and the bluish colour of a very early star, the blue colour in this case being due to the carbon radiation in the blue. This condition probably existed from May 12 to May 21. Afterwards, as the sparser swarm became very faint, the blue colour gradually died out, leaving a yellow tint preponderating.

The compound of colours is, perhaps, more obvious in this case than in any other, and the reason is not far to seek, since the two swarms were of such very different degrees of condensation, one being comparatively far advanced along the temperature curve, whilst the other was only a very sparse swarm, as indicated also by the compound spectrum.

Nova Cygni.

The observations of the colours of this star by Dr. LOHSE* show that the changes were very similar to those observed by TYCHO BRAHE in the Nova of 1572. The colours observed on various dates were as follows :—

24th November, 1876 . .	Golden-yellow, almost red. (SCHMIDT, 'Astr. Nachr.,' 2113.)
5th December „ . .	Orange colour. (VOGEL, 'Berlin Monatsber.,' 1877.)
8th „ „ . .	Colour scarcely different. (VOGEL, 'Berlin Monatsber.,' 1877.)
26th „ „ . .	Of a reddish colour. (VOGEL, 'Berlin Monatsber.', 1877.)
2nd January, 1877 . .	Decided red colour. (COPELAND, 'COPERNICUS,' vol. 2, p. 102.)
8th „ „ . .	Red, *with tinge of purple!!* (COPELAND, 'COPERNICUS,' vol. 2, p. 102.)
19th „ „ . .	Much less red, hardly full orange. (COPELAND, 'COPERNICUS,' vol. 2, p. 102.)
7th February „ . .	Deep orange. (COPELAND, 'COPERNICUS,' vol. 2, p. 102.)

It will be seen that the changes in colour of Nova Cygni are in exact conformity with those given at the beginning of this note, and it will also be seen that Nova Cygni did not reach so high a temperature as Nova Coronæ; for, whereas the latter star was bluish-white at its brightest and hottest stage, Nova Cygni was of a golden yellow. This fact is also borne out by the spectroscopic observations of the two stars.

The purple tinge noted by COPELAND on January 8 was, no doubt, produced by the addition of the blue or bluish-green light of the sparser regions to the reddish light of the denser parts of the swarm.

Referring to these observations of colour, Dr. LOHSE remarks: "The spectroscope gives the desired explanation. It showed that the continuous spectrum, which was at first exceedingly bright, gradually became pale, until at last scarcely anything but bright lines could be seen. This succession of appearances, as seen in both TYCHO'S and SCHMIDT'S stars, and which will probably occur in all stars of a similar kind, shows distinctly that a series of materials came into action requiring varying degrees of heat to set them aglow, and thus causing a dying-out of certain colours in the spectrum."

Nova Andromedæ.

The colour changes of this star observed by COPELAND, HUGGINS, and others, are also exactly what they would be in a meteor-swarm running backwards along the temperature curve. The changes have not a very great range, as the star was only visible for a short time, and never reached a high temperature. The colours observed were as follows :—

* 'Berlin Akad. Monatsber.,' 1877, p. 826.

1st Sept. . .	Yellowish. (COPELAND, 'M. N.,' vol. 47, p. 53.)
1st Sept. . .	Reddish-yellow. (KONKOLY, 'A. N.,' 268.)
3rd Sept. . .	Orange colour. (HUGGINS, 'Brit. Assoc. Rep.,' 1885, p. 935.)
3rd Sept. . .	Full yellow. (COPELAND, 'M. N.,' vol. 47, p. 53.)
6th Sept. . .	Yellow. (LOHSE, 'M. N.,' vol. 46, p. 300.)
9th Sept. . .	Reddish. (STONE, 'M. N.,' vol. 46, p. 56.)
9th Sept. . .	Slightly redder than formerly. (LOHSE, 'M. N.,' vol. 46, p. 300.)
9th Sept. . .	Less strongly orange. (HUGGINS, 'Brit. Assoc. Rep.,' 1885, p. 935.)
17th Sept. . .	Yellowish-red. (STONE, 'M. N.,' vol. 46, p. 56.)
30th Sept. . .	Slight orange flush. (MAUNDER, 'M. N.,' vol. 46, p. 21.)

The general sequence of colours may therefore be taken as reddish-yellow, orange, reddish, and yellowish-red, which closely agree with the portion of the colour sequence reddish-yellow, yellowish-red, red, yellowish-red. The compounding of the colours of the two different swarms in this star is not very obvious, as both swarms were at a low temperature.

General Conclusions with regard to Colour.

It will be seen from the preceding that the changes of colour observed during the cooling of Novæ are perfectly in accordance with the sequence to which reference has been made. In one case, the temperature is increasing, while, in the other, it is decreasing, and the changes accordingly take place in inverse order. The Nova observed by TYCHO BRAHE, appears to have reached an exceptionally high temperature, as indicated by its colour and brightness, and the changes of colour observed are exactly what they would have been in a cooling swarm of meteorites. This also was the case in the other Novæ of which colour observations have been recorded. Nova Cygni passed from a golden yellow to red, and then to orange, which agrees with the portion of the general colour sequence—reddish-yellow, yellow, red, yellowish-red.

Nova Andromedæ was first reddish-yellow, then orange coloured, reddish, and yellowish-red. Many observations of variations in the colour of Nova Coronæ have been made, and these show that from bluish-white it ran down to a dull yellow. From these observations of colour it is evident that this was the hottest of the new stars. The "white, with a bluish look," recorded by BAXENDELL, is at the top of our colour stages, and the spectroscopic examination of the star indicated a high temperature. BAXENDELL noted that, after the first observations, no blue tinge was seen.

The discussion of colour observations therefore strengthens the view that new stars are complex bodies, probably produced by the collision of two swarms of different densities.

VIII. Carbon Radiation in Novæ.

In a former paper* I showed that the record of the presence of bright carbon flutings was unbroken from a planetary nebula through stars with bright-line spectra to those resembling α Herculis; that is entirely through Groups I. and II. of my classification. In comets, also, carbon is one of the chief features of the spectrum, and here there can be little doubt that we are dealing with swarms of meteorites.

Carbon is thus one of the chief characteristics of the spectra of uncondensed meteor swarms. We have already seen that there is evidence of its existence in Novæ, but to emphasise this point, it may be convenient to summarise the observations which demonstrate it.

In Nova Coronæ the evidence depends upon two lines in the blue at approximately λ 467 and 473. The more refrangible was stated by Dr. Huggins to be either double or ill defined, and this was no doubt the maximum of luminosity of the compound carbon fluting at 468. The line at 473 was probably the least refrangible maximum of the same group. This double maximum of the carbon fluting has frequently been recorded in cometary spectra. The green flutings of carbon in Nova Coronæ were masked by the continuous spectrum, which, however, did not extend far enough into the blue to mask the other.

This double maximum was also seen by Vogel in Nova Cygni soon after its appearance, but after a time the sharp termination at 474 ceased to be visible, and the more refrangible one remained alone. Both these conditions have frequently been recorded in comets, and there is no doubt that they were due to carbon. In Nova Cygni, however, there was other evidence of carbon in the appearance of the brightest fluting at 517. Both this and the one at 468 faded away as the star gradually assumed the spectrum of a planetary nebula.

For Nova Andromedæ we have Copeland's statement that the spectrum was "the same as that given by any ordinary hydrocarbon flame." Although the flutings seen exist also in the nebula, it is probable that they were slightly intensified in the Nova, because the same observers did not note them in the nebula itself. Some of the observers, however, noted that the spectrum of the Nova was that of the nebula intensified, although they did not recognise the true character of the nebula spectrum.

Again, a characteristic feature of the spectra of Novæ at some period is the apparent breaking up of the blue end of the spectrum in two parts. Thus, speaking of Nova Cygni, Vogel† says: "It must be also mentioned as characteristic of this spectrum that the blue and violet were very distinct compared with what they are in other stars possessing a band spectrum;" and with respect to an observation made on January 1, he further remarks: "After F followed a broad dark band which divided the spectrum into two parts," as behind it the continuous spectrum, although very

* 'Roy. Soc. Proc.,' vol. 47, p. 39.

† 'Berlin Akad. Monatsber.,' 1877, p. 241.

weak, is still further visible. A little later, he states that the dark band had a wave-length of 474–486.

CORNU* also shows the spectrum of Nova Cygni divided into two parts beyond F, and Dr. LOHSE† noted what he considered to be an intensely dark absorption band beyond F.

Again, KONKOLY noted regarding Nova Andromedæ,† "Shortly behind the region of F the spectrum is just as if cut off."

In all these cases, the apparent breaking-up of the spectrum was doubtless due to the existence of the bright blue fluting of carbon standing out beyond the end of the continuous spectrum, exactly as is seen in the spectra of bright-line "stars" and some of the condensing swarms of Group II.

In the discussions of the spectra of condensing swarms‡ I remarked :—"When in these stars the spectrum is seen far in the blue, the luminosity really proceeds first from the carbon fluting, and, in the hotter stars, from the hydrocarbon one, which is still more refrangible, in addition. In the stars which have been examined so far, the dark parts of the spectrum, which at first sight appear due to absorption, are shown to be most likely caused by the defect of radiation in that part of the spectrum between the blue end of the continuous spectrum from the meteorites and the bright band of carbon."

In such cases as these just described the carbon fluting at 474 appears broken off from the remainder of the spectrum.

Speaking of LALANDE 13412, I remarked§ :—"The bright part of the spectrum extending from 473 towards the blue with its maximum at 468 is, I would again suggest, the carbon band appearing beyond the continuous spectrum"; and, again referring to 2nd Cygnus, "The bright band in the blue at 473 is most probably the carbon band appearing bright upon a faint continuous spectrum, this producing the apparent absorption from 486 to 473." In 3rd Cygnus the same thing occurs, a dark band appearing from about 488 to 473, which is doubtless nothing more than the dark space between the end of the continuous spectrum and the carbon fluting at 474. I also remarked, concerning the origin of the discontinuous spectrum|| :—"I have already shown that when the meteorites are wide apart, though not at their widest, and there is no marked condensation, the spectrum will extend farther into the blue, and therefore the flutings in the blue will be quite bright; in fact, under this condition the chief light in this part of the spectrum, almost indeed the only light, will come from the bright carbon. Under this same condition the temperature of the meteorites will

* 'Comptes Rendus,' vol. 83, p. 172.

† 'Astr. Nachr.,' No. 2681.

‡ Bakerian Lecture, 1888, p. 31.

§ Bakerian Lecture, 1888, p. 35.

|| Bakerian Lecture, 1888, p. 54.

not be very high; there will, therefore, be little continuous spectrum to be absorbed in the red and yellow."

There can be no doubt, therefore, that the spectra of Novæ are similar to the spectra of bodies of Group II., and the later species of Group I., as far as carbon is concerned. All these, again, are closely related to cometary spectra, and the acknowledged meteoritic nature of the latter strengthens the view that Novæ are produced by the collisions of meteor-swarms.

IX. General Conclusions.

In this paper I have endeavoured to bring together all the existing spectroscopic observations of Novæ. They show that the changes observed are very closely related to those observed in cometary spectra, the difference in observing conditions, and the compound character of Novæ being duly allowed for. The spectra in both cases indicate comparatively low temperatures. The temperature of a Nova depends upon the degree of condensation of the meteor-swarms which produce it. Its visibility depends also to a certain extent on its size. Hence it is that all Novæ do not attain the same maximum temperature or degree of visibility, and that some are lost to view before they descend to the same low temperature as others. A similar case is seen in comets which differ in their maximum temperature, according to their different perihelion distances.

But with Novæ, as with comets, a more or less complete sequence of spectra has been found by considering the whole of the spectroscopic observations, and joining them together on a descending scale of temperature.

The general result of the comparison of new stars with variables, is that in passing from a variable to a new star, we pass from one swarm (or many) revolving in an elliptic orbit round a central swarm, to one probably revolving in a parabolic or hyperbolic orbit.

The changes in magnitude observed in Novæ are also in strict accordance with the meteoritic theory of their origin. The sudden increase of luminosity, which denotes the creation of a new star, may well be due to the colliding of two swarms of meteorites, whilst the rapid fading away conclusively demonstrates, that small bodies and not large ones are engaged, for, as Dr. Croll notes in "Stellar Evolution," p. 33: "Suppose two bodies, each half the mass of the sun, moving directly towards each other, with a velocity of 476 miles per second; these bodies would, in virtue of that velocity, possess 4149×10^{38} foot-pounds of energy, which is equal to 100,000,000,000 foot-pounds per pound of the mass, and this converted into heat by the stoppage of their motions would suffice to maintain the present rate of the sun's radiation for a period of 50,000,000 years."

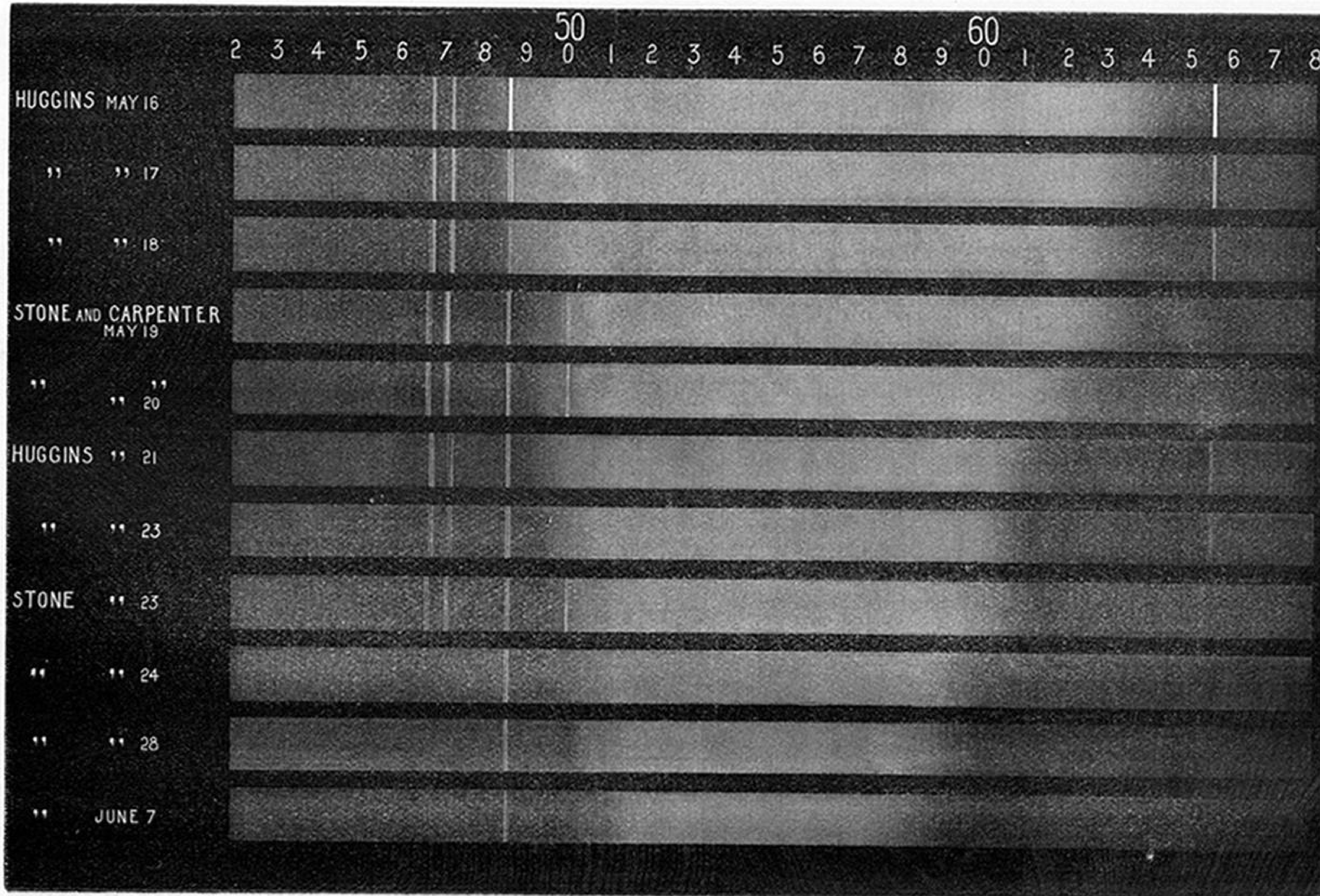
The complete discussion, therefore, tends to confirm the conclusion which I arrived at in November, 1887,* namely: "New stars, whether seen in connection with

* 'Roy. Soc. Proc.,' vol. 43, p. 154.

nebulæ or not, are produced by the clash of meteor swarms, the bright lines seen being low temperature lines of elements, the spectra of which are most brilliant at a low stage of heat."

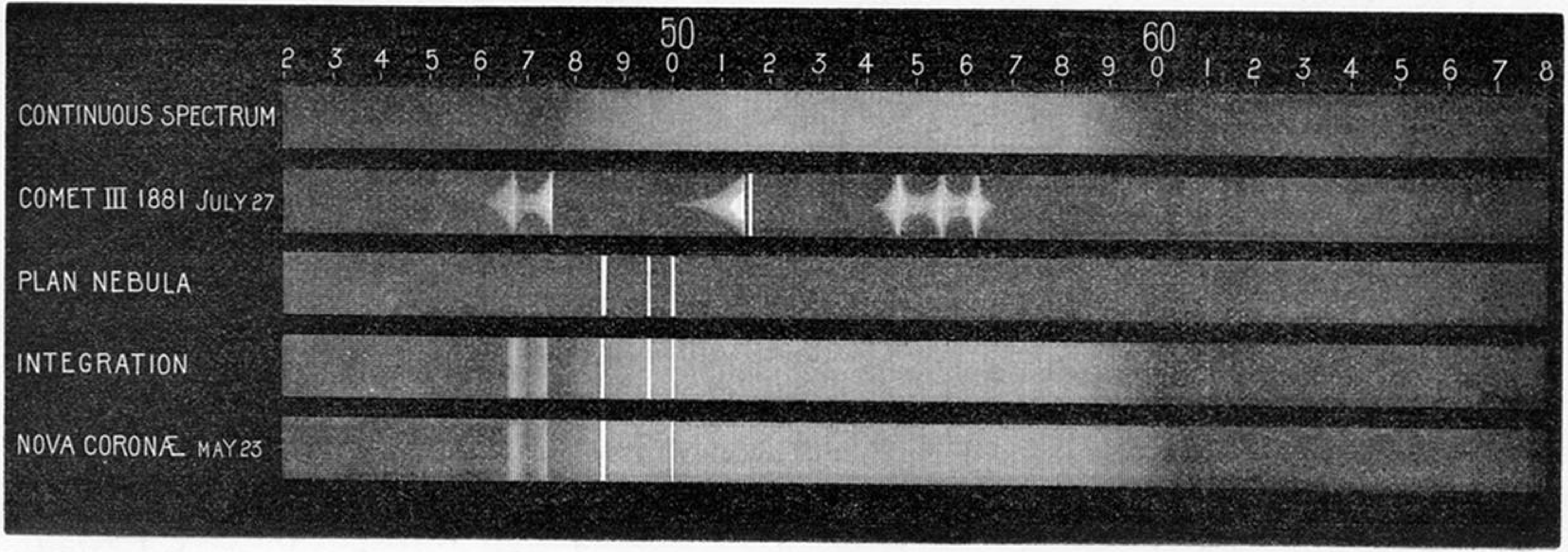
I have finally to express my obligations to my assistants, Messrs. FOWLER, BAXANDALL, and GREGORY. Mr. FOWLER has assisted chiefly in the discussion of the observations, Mr. BAXANDALL in the preparation of the maps, and Mr. GREGORY in looking up the records on the subject.

Fig. 1.



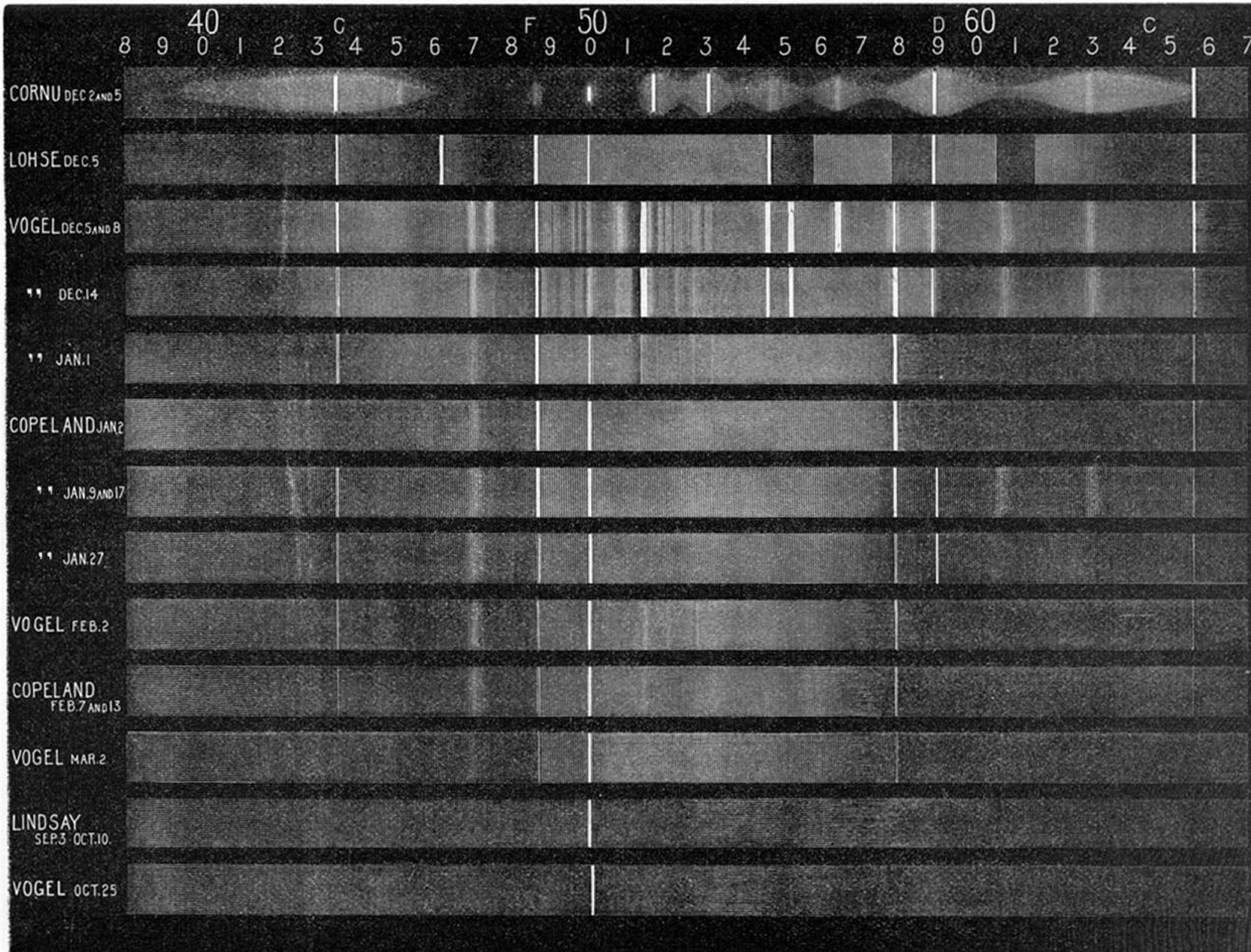
Spectra of Nova Coronæ.

Fig. 2.



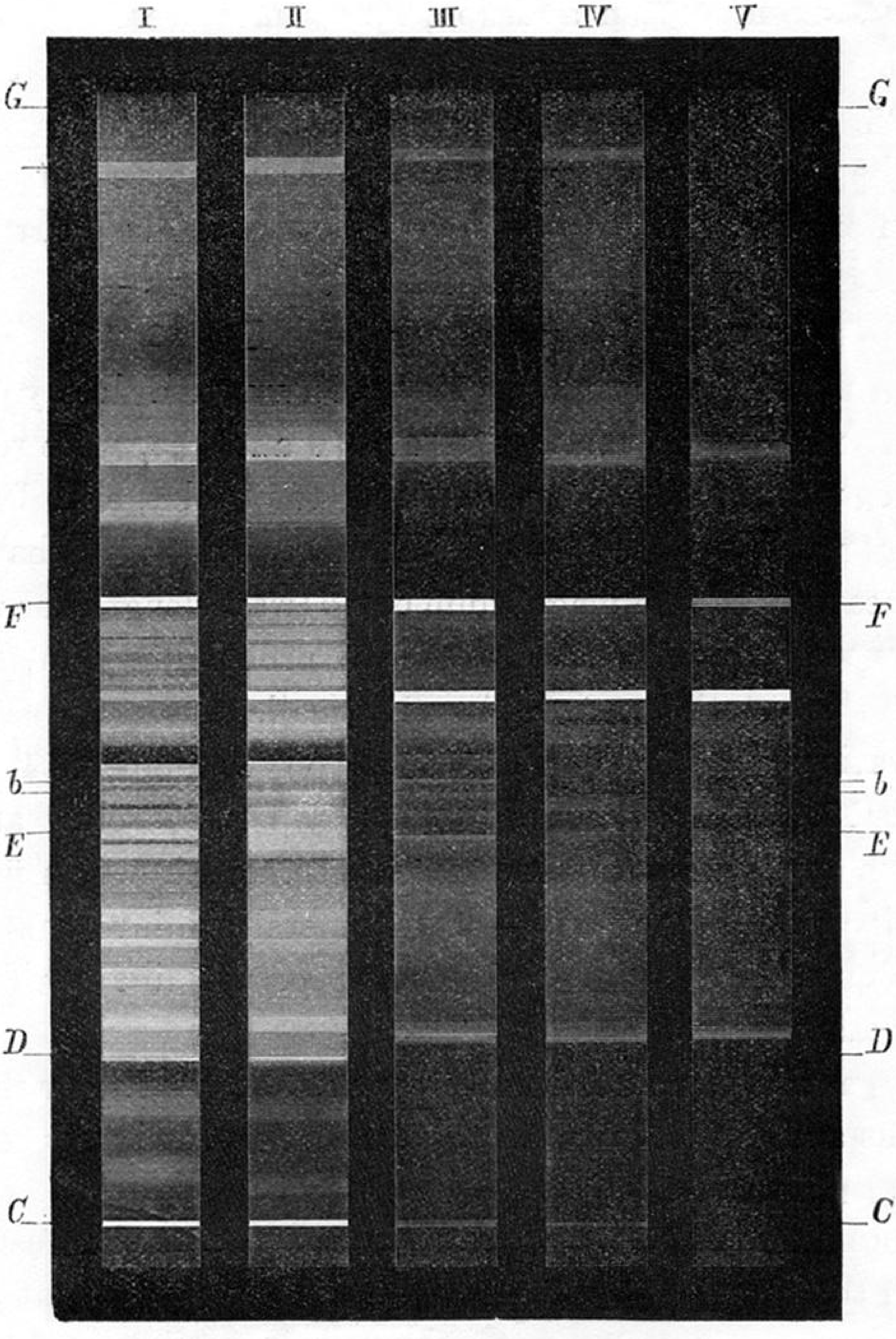
Integration of the spectra of COGGIA's comet and planetary nebula compared with spectrum of Nova Coronæ.

Fig. 3.



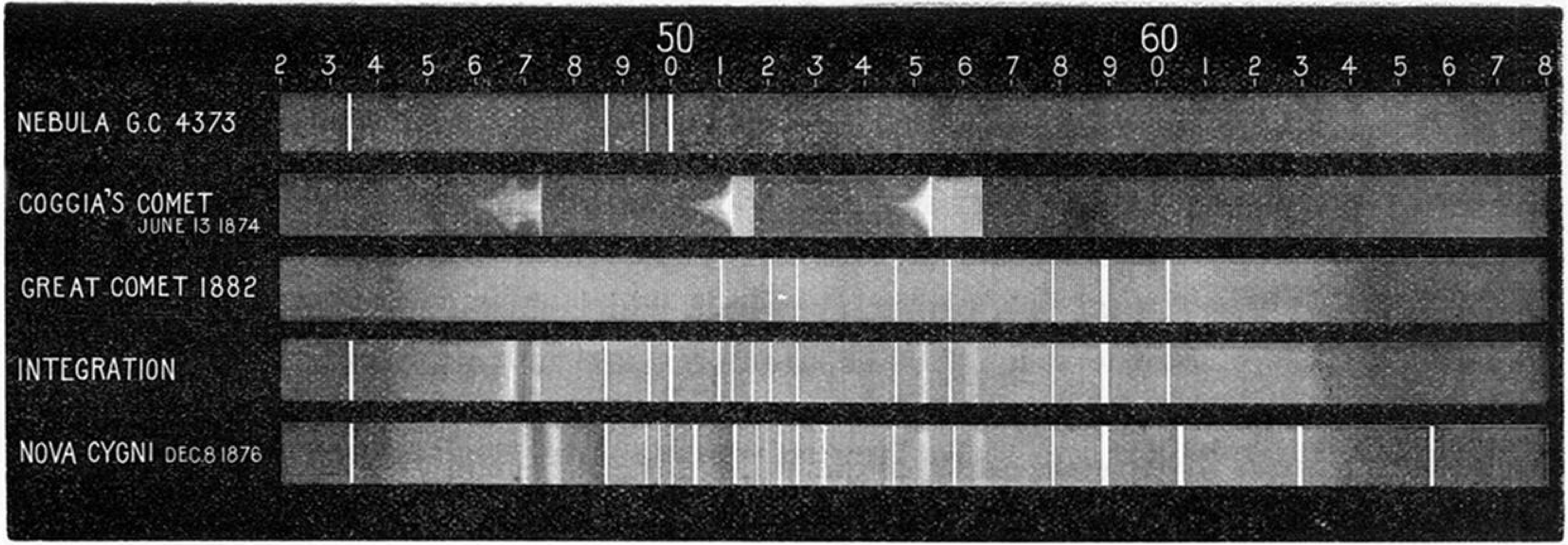
Spectra of Nova Cygni.

Fig. 4.



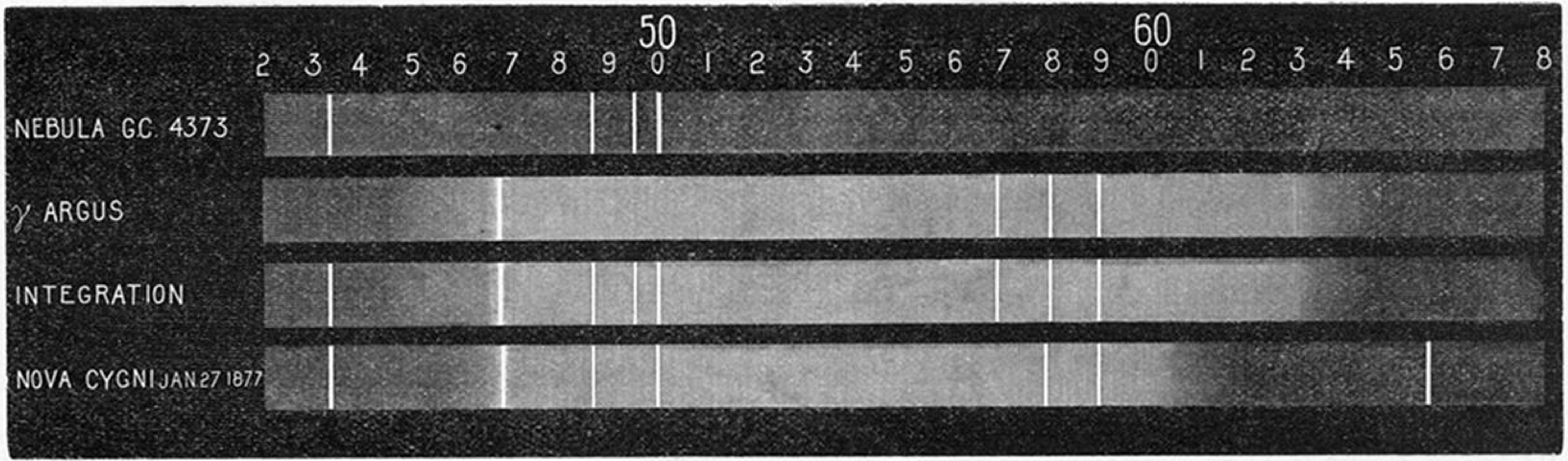
VOGEL's observations of Nova Cygni.

Fig. 5.



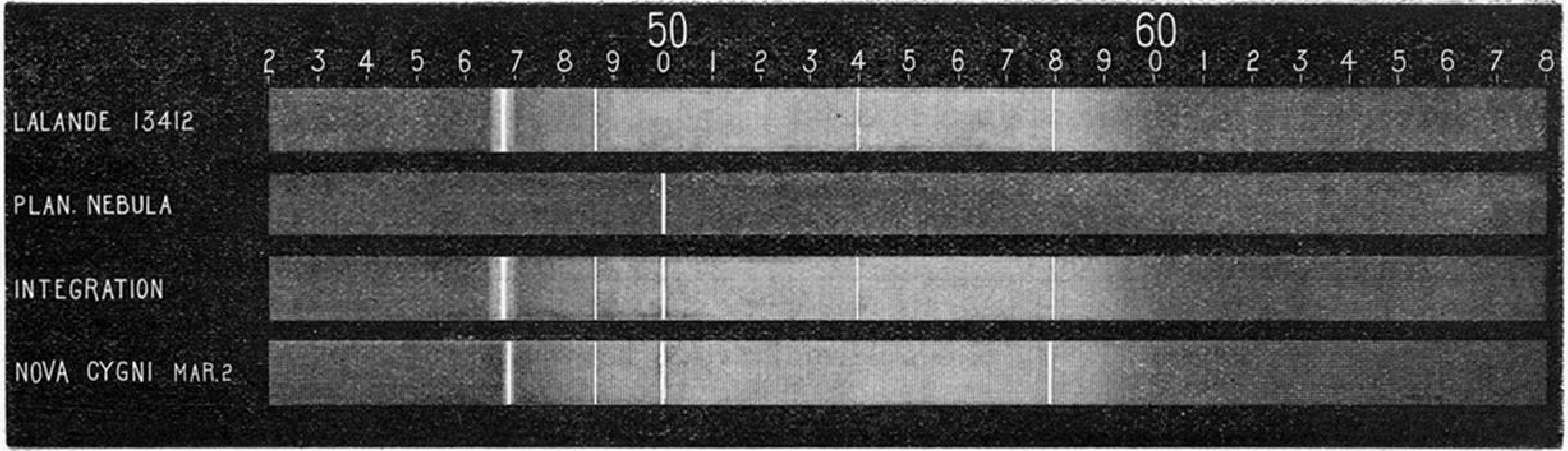
Integration of the spectra of comets and nebula, compared with that of Nova Cygni.

Fig. 6.



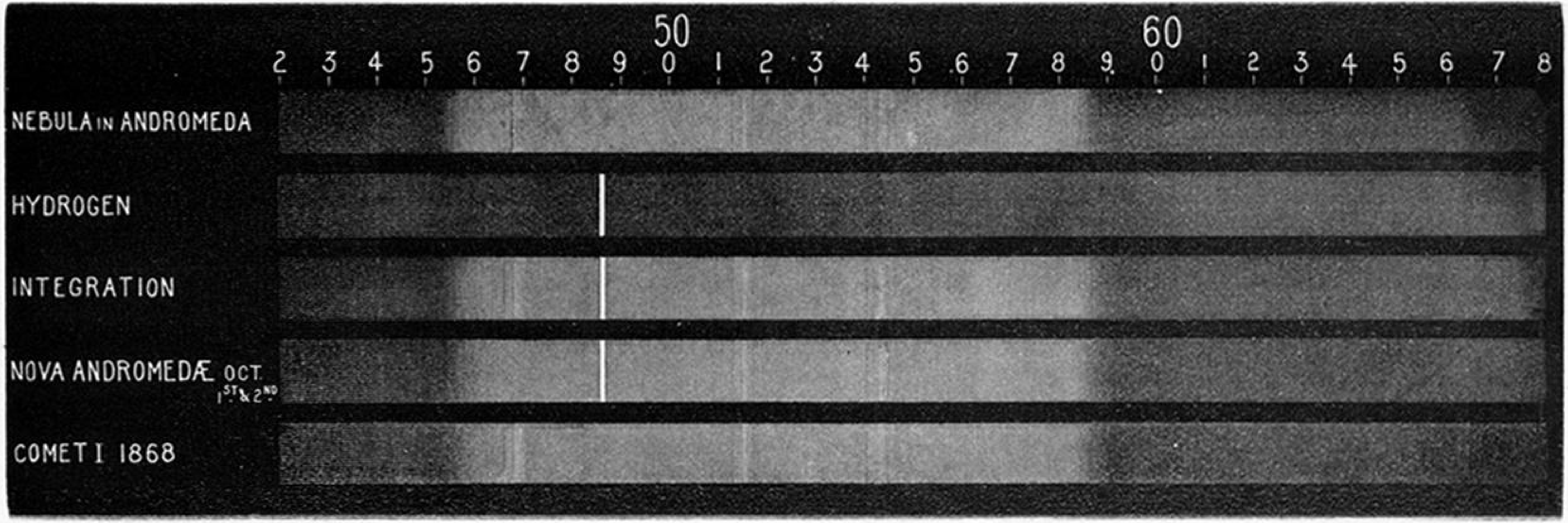
Integration of the spectra of nebula 4373 and γ Argûs compared with that of Nova Cygni.

Fig. 7.



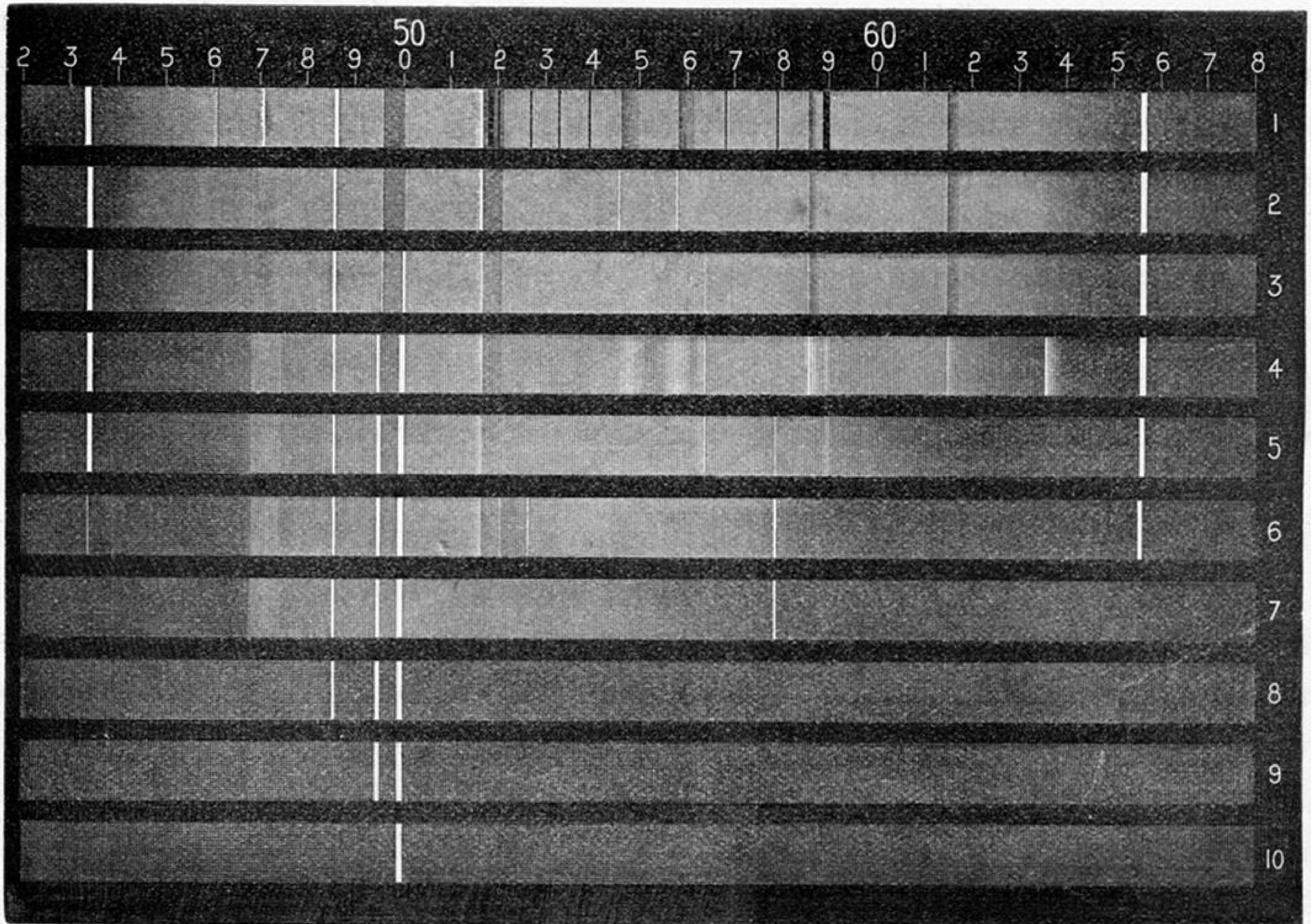
Integration of the spectra of a planetary nebula and LALANDE 13,412, compared with that of Nova Cygni.

Fig. 8.



Integration of spectra of the nebula in Andromeda, and of hydrogen, compared with that of Nova Andromedæ.

Fig. 9.



Sequence of spectra in Novæ.