The Spectrum of Nova Aquilæ. By J. Evershed, F.R.S.

(Plate 13.)

On June 10 a telegram was received at the Observatory, Kodaikánal, from Mr. C. L. Dundas, I.C.S., of Jhelum, N. India, informing me of his discovery of a nova near Aquila. The star was first seen by him at $3^h\ 30^m$ a.m. Indian Standard Time on the morning of June 9, or 10 p.m. G.M.T. on June 8; and he estimated the magnitude as equal to Altair. Mr. Dundas later gave me interesting details of his observations of the spectrum, which he observed on the night of June 10–11, when the star was estimated as magnitude 0·4. On this date, in addition to the bright hydrogen lines, he noted absorption lines in series, sharp towards the violet. Two nights later the hydrogen lines had developed enormously, and there was "little yellow in the spectrum and not much intervening between the green and the crimson."

The telegram from Mr. Dundas was the first intimation I received of the nova, which was, however, discovered independently about six hours earlier by Mr. G. N. Bower at Madras. He observed it between 9 and 10 p.m. on June 8, or between 3.30 and 4.30 p.m. G.M.T. June 8. This, so far as I know, is the earliest observation of the nova, and Mr. Bower also estimated its magnitude at that time as equal to Altair.

Instruments Employed.

At Kodaikánal, photographic work on the spectrum was attempted immediately, as it was considered of importance to secure records of the earlier stages; the star was extremely well placed for observation, passing within 10 degrees of the zenith at culmination. The first photograph was secured on June 10–11 about midnight, or June 10, $6^h\ 30^m$ G.M.T. The 15-inch Hyderabad lens was used in conjunction with the 18-inch siderostat, and the prism spectrograph built last year for work on Venus. The spectrum is a very imperfect one owing to the steep colour curve of the 15-inch lens in the violet, but it is of interest in showing no defined bright lines or bands but only a continuous spectrum with faint groups of absorption lines. The night of June 11 was wasted in a futile attempt to get a second-order grating spectrum with iron arc comparison, the grating spectrograph being already in adjustment for photographing Venus spectra. By the use of a shorter camera than is used for Venus and an exposure of four hours, a feeble image was obtained showing an ill-defined band corresponding to $H\gamma$ emission.

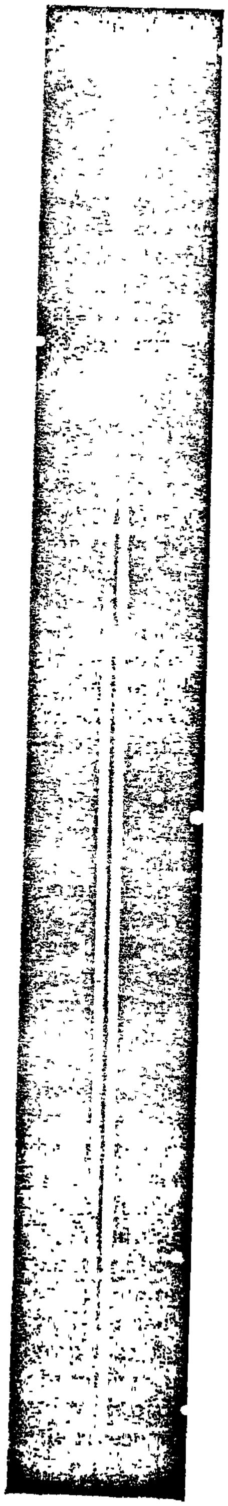
On June 12 the prism spectrograph was rearranged and transformed into a prismatic camera of 6-inch aperture and 7 foot 6 inch focal length. A 6-inch photo-visual lens by Cooke was arranged as camera lens, and the full aperture used of the two excellent 45° prisms acquired from the dismantled Poona Observatory. The prism box, with sand-bag packing to secure uniform temperature, was ready for immediate use; but the camera had to be improvised, and the adjustments for focus and inclination of plate, always troublesome in a slitless instrument, could not be perfected in time for the first photographs exposed on the night of June 12–13. In these the focus is perfect only in the less refrangible region between D and F, but there is much interesting detail visible also in the violet region as far as $H\delta$.

By the night of June 13–14 the camera had been correctly adjusted and the guiding arrangements also perfected, so that from this date a very interesting series of spectra was secured; these are over 4 inches in length (104 mm.) between $H\beta$ and $H\epsilon$, and at the red end they include $H\alpha$ photographed on a separate strip of red sensitive plate placed at the end of the slide. On most of the plates a comparison spectrum of Arcturus is impressed, from which the wave-lengths of the nova lines can be determined. On June 20 a small prismatic camera of 2-inch aperture and 2 feet 6 inches focus, with two 60° prisms of ultra-violet glass, was arranged in the beam of light from the 18-inch siderostat. The photographs obtained with this camera are on a scale less than one quarter those of the larger instrument, but they show the ultra-violet region as far as Ho.

As both prismatic cameras were worked simultaneously, the comparison spectrum of Arcturus appears on the small-scale spectra exactly as in those taken with the 6-inch camera.

The guiding arrangements and the method of photographing a comparison spectrum are, I think, new, and as they have proved very effective, a short description may not be out of place. The prismatic cameras were fixed in a horizontal position with the prism edges vertical; it was necessary therefore to give the star a vertical movement in order to broaden the spectrum. This was effected in the following way: the prism box containing the two 6-inch 45° prisms is mounted on a movable carriage running on iron rails passing directly in front of the 12-inch image-forming lens of the spectroheliograph. When the prismatic camera is to be used the prism box is run into position directly in front of this lens, and clamped centrally with respect to the beam of light from the 18-inch siderostat. In this position it obstructs most of the light falling on the lens, but two small segments receive light passing above and below the prisms; these together have an area of 12 square inches, which is quite sufficient to form a bright and well-defined image of a star on the slit plate of the spectroheliograph, 21 feet distant. A mirror was therefore arranged to reflect this image into an eye-piece having a finely ruled glass réseau in its focal plane. By the aid of a plumb line and a pair of lenses the réseau was easily adjusted with its rulings truly vertical and

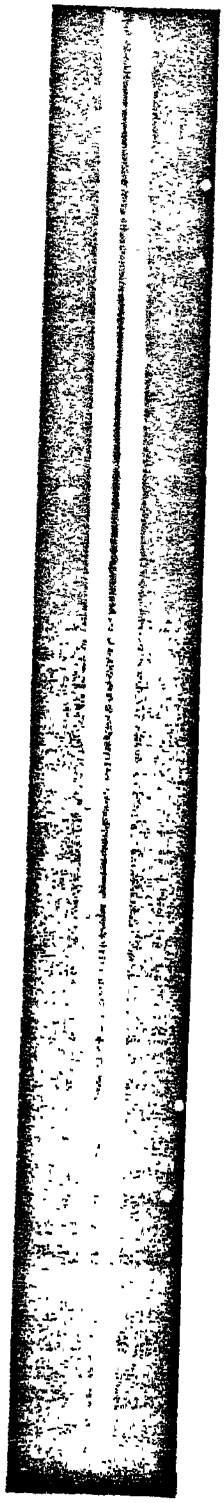
Altair. 1918 June 14, $12^h\ 57^m$ to $1^h\ 25^m$.



Nova Aquilæ. 1918 June 13-14, $11^h\ 30^m$ to $12^h\ 44^m$.

Fig. 1.

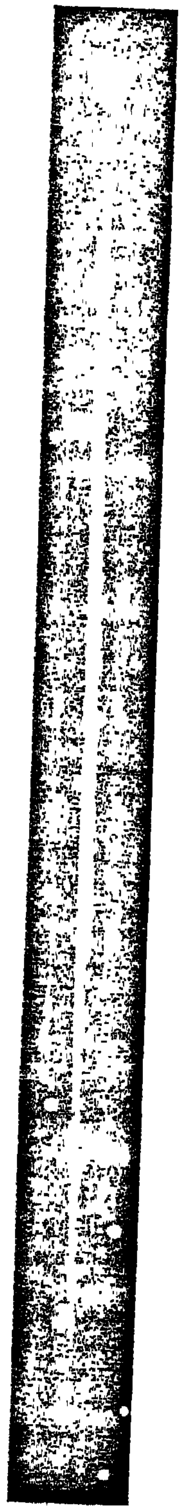
Arcturus. 1918 June 19, $9^h\ 25^m$ to $9^h\ 44^m$.



Nova Aquilæ. 1918 June 19 20, $9^h\ 51^m$ to $0^h\ 28^m$.

Fig. 2.

Nova Aquilæ. 1918 June 18-19, $10^h\ 50^m$ to $0^h\ 57^m$.



Arcturus. 1918 June 18, $10^h\ 32^m$ to $10^h\ 50^m$.

Fig. 3.

horizontal. The guiding then consisted in bringing the star to the central vertical line near the top of the field of view and allowing it to drift slowly downward through an interval defined by the horizontal lines, and repeating this operation as many times as needed to secure a fully exposed spectrum photograph. To get a *uniform* downward drift the siderostat axis was put out of adjustment in azimuth by a definite amount; then in guiding the declination slow motion was not touched during the exposure and attention was concentrated on holding the star on the line by means of the R.A. slow-motion motors only, the driving clock being also regulated so that the least amount of deviation should occur.

For the comparison spectrum, it was merely necessary to bring the star whose spectrum it was desired to place beside the nova spectrum to the same central line of the réseau, but in a different part of the field. The exposure was made either before or after the exposure on the nova; but if great accuracy were required, the exposure might have been made both before and after that on the nova, to eliminate the effects of temperature change in the prisms.

The focal length of the 12-inch lens being nearly three times that of the large prismatic camera, and over eight times that of the smaller instrument, errors of guiding are reduced proportionately; so that not only is it possible to secure well-defined spectral images, but also a very accurate alignment of the comparison spectrum, provided no temperature change has occurred in the prisms between the successive exposures.

The three spectra reproduced in Plate 13 show the character of the spectra obtained with this apparatus. Fig. 1 is the mixed spectrum of dark lines and bright bands obtained on June 13, $6^h\ 37^m$ G.M.T. Fig. 2 is the spectrum of June 19, $4^h\ 04^m$ G.M.T., and shows the sharp boundaries of the hydrogen bands, particularly $H\beta$. Fig. 3 is the first of the series obtained with the 2-inch prismatic camera. The times on the plate are in I.S.T.

Unfortunately for the Kodaikánal results, the seeing was excessively bad throughout the month of June, and this of course set a limit to the definition of the spectrum lines. It was as bad near the zenith as elsewhere, and on many nights the image of Arcturus would constantly expand to a trembling disc 15″ in diameter; and sudden displacements of many seconds of arc, impossible to avoid by anticipation, were even more exasperating. This was not due to irregular driving of the clock, but to refraction changes due to the chaotic state of the air above the mountain—one of the serious drawbacks of a mountain top in a tropical climate which is much disturbed by monsoon winds.

The photographs reveal these irregularities in small distortions of the lines in the Arcturus spectra. In the nova spectra, which are built up by several successive traverses of the star, the lines are widened and diffused by the bad definition.

In the work of arranging the apparatus for the nova and making the exposures I had the very able assistance of the late Mr. R. J. Pocock, Director of the Nizamiah Observatory, who was visiting the Kodaikánal Observatory at the time. The réseau in the guiding eye-piece was his suggestion; and it was due to his very resourceful help that we were able to get all the arrangements perfected by the evening of June 13.

Owing to the failure of the monsoon in Southern India, the weather was exceptionally clear; that is, in the 34 nights from June 8 to July 11 inclusive, about 12 were clear and 6 more or less hazy. Excluding the first two unsuccessful attempts on June 10 and 11, good photographs were secured on 12 nights, and particulars of these are given in the following list:—

Date.	G.M.T. of Mid-exposure.	Duration.	Star.	Remarks.
1918.	h m	m		
June 12	(1) 4 42	60	Nova.	Clear sky, definition poor
	5 30	15	Arcturus.	
	(2) 6 30	40	Nova.	
	7 07	25	Altair.	,,
13	6 37	74	Nova	
	7 41	28	Altair.	,,
16	9 49	92	Nova.	Much interruption from hazy cloud, definition atrocious.
	10 54	2	Venus.	
	11 25	41	Nova again.	
18	(1) 3 51	79	Nova.	Definition very bad, image of Arcturus = Venus in size although in zenith.
	4 21	14	Arcturus.	
	(2) 5 11	18	Arcturus.	Nova exposure interrupted by much hazy cloud.
	6 26	121	Nova.	
19	4 04	19	Arcturus.	
	5 39	157	Nova.	
20	4 23	23	Arcturus.	
	5 50	119	Nova	
23	5 33	33	Arcturus.	Clear throughout.
	7 08	135	Nova.	
July 2	4 24	23	Arcturus.	Cloudy, 1 prism only used from this date.
	5 42	116	Nova.	
3	5 06	29	Arcturus.	Sky not clear; exposure interrupted by hazy cloud, definition fair.
	5 56	57	Nova.	
4	10 33	45	Nova only.	Hazy cloud.
6	5 11	38	Arcturus.	Clear throughout, definition fair.
	7 21	148	Nova.	
11	4 01	84	Nova.	Clear throughout.
	5 02	19	Arcturus.	

On June 18 the small prismatic camera was operating, and from this date a double set of photographs was obtained. All the large-scale plates photographed in July were obtained with a single 45° prism instead of the two used in June, when the star was bright enough to admit of the higher dispersion.

Magnitude Observations.

The varying magnitudes of the Nova were estimated by Mrs. Evershed as follows:—

Date. 1918.	G.M.T. h m	Magnitude.	Remarks.
June 10	6 00	0·4	Sky hazy.
10	10 30	0·2	Clear.
11	4 25	0·6	,,
16	11 30	2·1	Sky hazy.
18	3 30	2·0	Clear.
20	6 00	2·1	,,
23	6 30	3·0	,,
July 2	6 30	3·4	Fair.
4	8 30	2·8	Hazy.
6	6 10	3·2	Clear.
9	10 45	3·6	Star low in west.
12	11 02	4·4	,, ,,
15	4 00	4·3	Clear.
15	10 50	4·0	Doubtful owing to low altitude.

The stars used for comparison and their assumed magnitudes were:

Star.	Magnitude.	Star.	Magnitude.
Vega	0·1	ζ Aquilæ	3·0
Altair	0·9	η Serpentis	3·4
θ Scorpii	2·0	λ Aquilæ	3·6
σ Sagittarii	2·1	β Aquilæ	3·9
γ Cygni	2·3	θ Serpentis	4·5
γ Aquilæ	2·8	ω Aquilæ	5·1

Determination of Wave-Lengths.

Of the spectra obtained six were selected for measurement, viz. those photographed on June 12, 13, 19, 20, July 6 and 11. The results are collected in Tables I., II., and III. at the end of this paper. Each table gives the wave-lengths and intensities for two consecutive dates; in Tables I. and II. the intensities are for the absorption lines only, and Table III. for the emission bands only, absorption lines being practically absent in the July plates.

In Table I. the wave-lengths are derived from the position of the hydrogen lines β, γ, and δ in Altair, assuming the wave-lengths to be 4860·7, 4339·9, and 4101·2 respectively, corresponding to a motion of the star of −49·6 km./sec. towards the Earth. This velocity is the sum of the radial velocity −33 km./sec., and the component of the Earth's orbital motion −16·6 km./sec.

In Table II. the wave-lengths are derived from the numerous known lines in the spectrum of Arcturus. The wave-lengths of these are taken from Rowland's table of solar lines, increased by an amount corresponding with a radial velocity of +17·4 km./sec., Arcturus radial velocity being −5·8 km./sec., and the component of the Earth's velocity on June 20–21 +23·2 km./sec.

In Table III. the wave-lengths are also derived from the spectrum of Arcturus, but the component of the Earth's velocity being greater in July, a correction to the Arcturus lines corresponding with +21 km./sec. has been applied.

The wave-lengths in all the tables are subject to a correction for the component of the Earth's orbital velocity in the direction of the star of −9·8 km./sec. on June 13–14, −6·8 km./sec. on June 20–21, and +2 km./sec. on July 6–11.

The wave-lengths in all cases have been determined by graphical methods, using the numerous known lines in the spectrum of Arcturus to form a dispersion curve. In this work Mr. Sitarama Ayyar has given me valuable assistance. In order to identify with certainty the star lines or groups of lines with solar lines, especially in the difficult region between 4415 and 4860, a good solar spectrum taken with a narrow slit and having nearly the same dispersion as the star spectrum was found to be indispensable.

In the first and third columns in the tables an emission band is distinguished from absorption lines by a vertical line connecting two or more wave-lengths, these marking the approximate limits of the band, or the limits of the region of greatest intensity. These limits are in many cases very ill-defined, especially in the region between Hβ and Hγ. The limits of the hydrogen emission-bands are ill defined on June 13 and 14, but remarkably well defined on all later dates when photographs were obtained, that is, from June 16 to July 11.

The Absorption Spectrum of Hydrogen.

The two plates of June 12 show a double series of hydrogen absorption lines, separated by 10 to 12 angstroms, and displaced towards violet by amounts equivalent to velocities in the line of sight of nearly 1600 km./sec. and 2200 km./sec.

On the 13th the double series is again seen, and the more refrangible set of lines have widened on the side towards violet, Hβ being very definitely bounded and ·9 A. in width. On account of this widening, the centres of the lines are still further displaced to the violet. In the next plate, taken on June 16, the more refrangible absorption lines have disappeared, and of the less refrangible series Hα and Hβ are absent, Hγ is faint, and Hδ strong. On the 20th the lines have become indistinctly double, and on the 23rd the lines γ and δ have narrowed, owing to the disappearance of the more refrangible component. This is the last plate taken in June, and in July even Hδ had almost disappeared. On July 6 a small-scale plate shows Hδ faintly, and almost in the same position with reference to the Arcturus lines as on the 23rd, but its precise wave-length cannot be determined, as the small prismatic camera was not specially protected against temperature change, as was the larger instrument.

The most reliable values of wave-length and velocity have been obtained from the Hδ line, owing to its strength and the higher dispersion compared with Hβ and γ. The wave-lengths and deduced velocities for Hδ on the different dates in June are given below.

Date.	λ.		Km./sec.	
	a.	b.	a.	b.
1918 June 12	4080·2	4071·9	1586	2193
13	4079·6	4068	1630	2478
16	4078·8		1689	
18	4078·1		1740	
19	4077·9		1754	
20	{4076·9 4078·3		{1828 1725	
23	4078·1		1740	

The velocities here shown are subject to a correction for the component of the Earth's orbital velocity, which is -10 km./sec. on June 12 and decreases to $-5·6$ km./sec. on June 23. Measures of the lines β and γ in these plates show that the displacements are approximately proportional to wave-length, but this relation is best seen in the plate of June 19, in which Hϵ can be measured. For this plate I get the following values:—

	Hγ.	Hδ.	Hε.
Normal wave-lengths	4340·6	4101·9	3970·2
Observed wave-lengths	4315·4	4077·9	3947·0
Displacements	25·2	24·0	23·2
Displacement equivalent to 1753 km./sec. .	25·37	23·98	23·21

The greatest discordance here shown is in the Hγ displacement, but this line is the least satisfactory to measure. I have no hesitation in ascribing these large displacements to motion in the line of sight, as no other explanation seems to me in any degree satisfactory, and the movements are not more than two or three times greater than those observed in solar eruptions.

Considerable accuracy has been obtained in the measurements of the δ line, and the velocity determinations are relatively correct to about 5 km./sec. for all the plates after June 13. There may, however, be a small systematic error affecting all the values due to errors in estimating the mean wave-lengths of groups of lines which appear in the spectrum of Arcturus as single lines. The measures of June 12 and 13 are less accurate, since they are dependent on measures of the broad and ill-defined hydrogen lines in the Altair spectrum.

The results show that there is a steady increase of velocity from June 12 to June 20, when the lines became double. It amounts to 44 km./sec. between June 12 and 13, and averages 21 km./sec. daily from June 13 to 19. There is a further increase of 22 km./sec. on June 20 if the mean velocity on this date is taken. On June 23 the more refrangible component of the double line has disappeared, and the less refrangible component indicates the same velocity as on June 18. Judging by the small-scale plates taken in July, it is probable that very little change took place in the wave-length of Hδ after June 23.

An acceleration of velocity is also recorded under *b* in the table above amounting to 285 km./sec. between June 12 and 13. This refers to the second set of absorption lines which disappeared between June 13 and June 16. The rapid fading of these lines, and the more gradual disappearance of the less refrangible series, suggests that independent masses of relatively cool hydrogen were being ejected from the star and dissipated in space: that is to say, enormous prominences were thrown out and moved with accelerating speed under the influence of a repulsive force. Observations at Kodaikánal have shown that the larger eruptive prominences on the sun move outward with accelerating velocity and become dissipated in space. The largest velocity I have measured in a mass of hydrogen leaving the sun is 457 km./sec. at a height of 6′ above the chromosphere, and the largest velocity deduced from displaced lines at comparatively low altitudes was 360 km./sec. If the hydrogen in a prominence were dense enough to remain visible by absorption at a height of a million miles above the sun, velocities of the order of 1000 km./sec. would certainly be recorded, owing to the acceleration. Fenyi has, in fact, observed velocities in the line of sight as great as 890 km./sec.*

If the motion of a solar prominence is due to light-pressure, much higher velocities are to be expected in the case of a nova, where the emission of light is so prodigiously great in the initial stages. The great reduction of light after the first week or so may account for the tendency of the velocity to become constant after June 23.

In the series of small-scale spectra the absorption lines of hydrogen can be traced as far as Ho on June 20, but they are extremely faint and narrow on July 6. On this date, beginning at Hδ, they can still be traced to Hλ. An interesting feature in the ultra-violet is the absence of any strong emission bands adjoining the absorption lines. Hζ shows more or less emission, but from this line onwards towards the smaller wave-lengths the dark lines stand on a nearly uniform background. The continuous spectrum appears to extend far beyond the theoretical limit of

* *Astronomy and Astrophysics*, **11**, 63.

the series of displaced lines, which would be at 3625. The hydrogen emission is evidently relatively weak in the ultra-violet, while the absorption is weak at the red end of the spectrum. In this the absorption differs from that of the solar chromosphere and prominences, in which $H\alpha$ is always the strongest line, the absorption decreasing towards the violet, and usually ending at $H\epsilon$.

The Emission Spectrum of Hydrogen.

The hydrogen bands in the nova are remarkable for their width and sharply defined limits, and for the unchanging wave-length of these limits from June 16 to July 6. The definition of the $H\beta$ band after June 13 is such that its edges may be measured with an error not exceeding ¼ A. I give in Table IV. the results of my measures of the three bands β, γ, δ on the different dates, with the mean positions of their centres; these remained practically constant throughout, and indicate a radial velocity of -83 km./sec. with reference to the Earth, or -78 km./sec. with reference to the Sun, if the displacement may be interpreted as motion. The last plate of the series, taken on July 11, shows a slight change in the position of the violet edges of the bands, which extend about 1½ A. further towards violet, the edges towards red remaining the same. The centres on this date are therefore shifted about 0·7 A. towards violet compared with the earlier plates.

It will be noted that the widths of the bands are very nearly proportional to wave-length, excepting that $H\beta$ is about 2 A. wider than this relation would indicate; but this is easily explained by the great density of the β image. The increased width of the less refrangible bands makes it quite certain that pressure is not concerned in the widening, for according to Rossi * the broadening by pressure of the hydrogen lines varies as the inverse third or fourth power of the wave-length, $H\delta$ widening twice as much as $H\beta$, whereas in the nova $H\delta$ is four-fifths of the width of $H\beta$. It seems probable that the widening must be due to motion, but if so, limiting velocities of about 1580 km./sec. in either direction are required. It may be mentioned in this connection that the $H\alpha$ line in the solar spectrum is about 1 A. in width, and is even more definitely bounded than the α band in the nova. This width is probably a temperature effect, due to molecular movements with limiting velocities of about 22 km./sec.

The internal structure of the hydrogen bands does not vary greatly in my series of spectra. On June 12 and 13 very little of this structure is visible, the intensity increasing towards the centres of $H\alpha$ and $H\beta$ with fair regularity. $H\gamma$ is also strongest in the centre, but the band is broken up by absorption lines superposed upon it. On the dates subsequent to June 13 these absorption lines have vanished, and the negatives show three

* *Astrophysical Journal*, 34, 302.

regions of greatest density in each band. The approximate positions of these maxima are as follows :—

Hβ	4857	4864	4882
Hγ	4337	4342	4356
Hδ	4098	4105	4118

On June 23 the structure is slightly modified by the presence on each emission band of a very obscure absorption line at 4854, 4334, and 4096, and in addition there is a rather marked reduction of density between the two less refrangible maxima in each band. The July plates show very feeble indications of the same three regions of greater density, but only in the ultra-violet, where the bands are not over-exposed. Thus, throughout the series of plates no striking changes have been recorded in the emission bands.

The Calcium Lines H and K.

The absorption line K, displaced nearly 23 A. to violet, is clearly shown in the small-scale spectra of June 18, 19, 20; it is slightly weaker than Hε or Hζ, and on the 23rd becomes weaker still. On July 6 it is very faint and ill-defined on the red edge of the emission band of Hζ. On June 18 there are traces also of an emission band, but this is not seen on the later plates. The calcium H line in these spectra is not separated from Hε.

In the large-scale spectra which include the region, a very narrow and faint absorption line is found superposed on the Hε emission band, and nearly coincident with H in Arcturus. This is seen on the plates of June 16, 19, 20, and 23, and on the plate of the 19th, which extends further in the direction of the ultra-violet: a similar fine line is found almost coincident with K in Arcturus. There are faint traces also shown on some of the plates of an undisplaced calcium line at 4227.

Measures of the line H give the following wave-lengths corrected for the displacement of the Arcturus lines :—

June	16	3968·4
	19	3968·3
	20	3968·5
	23	3968·2
	Mean	3968·35

The measures are somewhat uncertain, owing to the weakness of the reference lines in Arcturus in this region, and the mean wave-length may be subject to an error as large as ±0·1 A. The interest of the result lies in the very small displacement shown, which amounts to −0·28 A. compared with Rowland's values of H. This implies a velocity towards Earth of 21 km./sec., or, deducting the Earth's orbital motion of −7 km./sec. at the mean date, there remains a residual radial velocity with reference to the Sun of −14 km./sec.* If the sun is moving in the direction of R.A. 18^h,

* I have probably under estimated the displacement, as, according to Mr. Plaskett's measures, the radial velocity is about −19 km./sec.

Dec. + 30° at − 20 km./sec., the component in the direction of the nova is − 17 km./sec. It follows therefore that the calcium vapour has a very small or zero component of motion in the line of sight with respect to the nearer stars. It probably has no connection with the nova, and may occupy any portion of space between the Earth and the star.

Narrow absorption lines at H and K have been observed in the spectra of other novæ: measures by Campbell and Wright in Nova Persei gave values of velocity with respect to the sun between + 4·2 and + 7·7 km./sec. They also measured fine absorption lines at D, and these gave the value + 3·3 km./sec.;* but the component of the sun's motion in the direction of Nova Persei is appproximately + 4 km./sec.; so here again the calcium appears to have been almost at rest in the line of sight with respect to the sidereal system. In the case of Nova Geminorum No. 2, the fine lines H and K, the D lines, and several others were measured by Adams and Köhlschutter, who found a radial velocity of + 10 km./sec. with reference to the sun.† Here the component of the solar motion is + 9 km./sec., a still closer approach to a zero velocity in the calcium and sodium cloud.‡

The Iron Lines.

The principal enhanced lines of iron are certainly present in the spectrum of June 12 and 13 as a double series of displaced absorption lines, and the less refrangible line of each pair is accompanied on the side towards red by a broad emission band, as in the hydrogen series. In the green region two of these emission bands and their absorption lines were at first taken to be due to the helium lines 4922 and 5016, and the third band nearest the red end to the magnesium triplet *b*. But the absorption lines accompanying this last band are single, not triple, and certainly represent the pFe line 5169. If a correction is applied corresponding with velocities of 2150 km./sec. and 1550 km./sec. to the three pairs of absorption lines, they reduce to the wave-lengths of the three pFe lines, as is shown below.

Observed λλ. (Mean of June 12 and 13.)	Correction.	Corrected λλ.		pFe.
4888·2	+35·6	4923·8	4924·1	4924·1
4898·9	+25·4	4924·3		
4981·6	+36·2	5017·8	5018·2	5018·6
4992·6	+25·9	5018·5		
5133·3	+37·2	5170·5	5169·7	5169·2
5142·3	+26·7	5169·0		

* *Astrophysical Journal*, **14**, 280, 281, and *L.O. Bulletin*, No. 8.

† *Ibid.*, **36**, 308.

‡ I find that Hartmann was led to the same conclusion with reference to Orionis and Nova Persei, and there are several binary stars in the Milky Way in which the position of the H and K lines is consistent with the assumption of zero motion with reference to the sidereal system.

If it is assumed, therefore, that the absorbing iron has nearly the same velocity as the hydrogen, the corrected wave-lengths agree, within the limits of accuracy of the measures, with the three enhanced lines of iron in this region.

In the more refrangible region this interpretation is confirmed by the presence of displaced absorption lines and wide emission bands which correspond with the principal pFe lines. The emission bands persist after the absorption lines have disappeared, but become extremely faint in the July plates. The lines and bands identified with pFe are shown in Tables I., II., and III.

The more refrangible components of the pairs of lines die out after June 13, as in the hydrogen series; but the less refrangible components in the green region persist until June 19, and show a diminishing wave-length or increasing velocity, as indicated in the table following.

	λ 4924.	λ 5018.	Mean Velocity km./sec.
June 12	4898·7	4992·2	1563
13	4899·0	4993·0	1528
16	4895·6	4989·5	1738
18	4895·5	4989·5	1741
19	4895·1	4989·2	1762

The progression is not regular, probably owing to the uncertainty of the measures of very weak lines; but the mean velocity indicated increases about 200 km./sec. between June 12 and June 19. The hydrogen δ line gives values increasing from 1586 to 1750 km./sec. for the same dates. The iron vapour therefore shares in the accelerating movement of the hydrogen.

The enhanced lines of iron do not appear to have been recorded as a conspicuous feature in the early stages of previous novæ; but, judging by the comparative tables published by Lockyer,* they seem to be generally present as emission lines in the second or bright-line stage.

The Absorption Band at 4055 – 4067.

This band has undergone a very remarkable series of changes. It appears first on the plate of June 16 as an ill-defined and rather weak absorption band between 4057 and 4067. It is more pronounced on June 18, when two maxima are shown within it. On June 19, the double band is bodily shifted towards violet about 3 A. On June 20 it has returned to its original position; on the 23rd, it has again shifted rather more towards violet. On the next plate, taken on July 2, the band has changed from absorption to emission and occupies about the same position as on June 23. On July 3 it is again a very strong absorption band displaced to violet as before, and on the 4th it is much the same,

* Sir N. Lockyer, *On Some of the Phenomena of New Stars*, Publications of the Solar Physics Committee, 1914.

the spectrum being completely cut in two by the band owing to the entire absence of light at this point. On the 6th it is less dark but still in the same position as on the 4th, and on the 11th it has nearly vanished, showing very faintly as an emission band.

When most shifted towards violet the band occupied the position between 4053 and 4064 and when most shifted towards red it was between 4058 and 4069. This band does not appear to have been a striking feature in the spectrum of Nova Persei.

The Nebular Lines.

There is no distinct evidence of the presence of nebular emission lines before July 2 when the band at 4992–5046 becomes stronger than the band 4895–4950. These two bands in the green represent the enhanced iron lines 4924 and 5018, and possibly the helium lines 4922 and 5016 contribute some of the emission. They are of about equal intensity during June, and the increase of intensity of the less refrangible band in July, I consider is due to the development of the nebular line 5007 superposed on it. On July 11 this band has become very strong, with a maximum of intensity near the violet end at 4979. On this date also a weak band has appeared at 4930–4966, the greatest intensity lying between 4930 and 4946; this probably represents the nebular line 4959, with faint helium (4922) and pFe (4924) emission mixed with it.

Another emission band which became very intense on July 11 forms an extension towards red of the Hγ emission band. This band may possibly represent the helium line 4388, and a nebular line measured by Keeler at 4365; it is very faint on the earlier plates, and on July 11 it is less intense than Hγ. The region of maximum intensity lies between 4378 and 4389, but the band evidently extends towards violet until it becomes merged in the hydrogen band. A new band also developed on July 11 at 4683–4704, probably due to the chromosphere line 4686, and there are traces of what may be helium emission on the red side of this near 4713. The band 4446–4476 in Table III. is probably in part due to the helium line at 4471, and the 4026 helium line is also shown in Table III. by a band from 4020 to 4029. It is evident that helium emission developed in July concurrently with the appearance of the nebular line 5007.

The Dark-Line Spectrum of June 12–13.

Most of the wave-lengths recorded in Table I. have not been determined with greater accuracy than the nearest angstrom unit, partly on account of the ill-defined character of many of the lines, and partly because of the difficulty of reduction, when the only reference lines are the ill-defined hydrogen lines in Altair. Had Arcturus been photographed instead of Altair, much more accurate results could have been obtained. Doubtless a greater relative accuracy in the positions of the lines could be secured by further work on the plates, but this does not at present seem to be worth while in view of the fact that a more perfect series of plates has been secured elsewhere, covering the same intermediate stage between the dark-line and bright-line spectra. In this mixed spectrum there must always be uncertainty in the case of broad lines as to whether they represent groups of absorption lines or are merely spaces between the emission bands. I believe that the majority of the lines recorded in Table I. are genuine, but their identification is very difficult, owing to the uncertainty as to the displacements. Many have been identified with pFe, on the assumption of a double series of lines displaced the same amounts as are the hydrogen lines, this being clearly justified by the results of the more accurate measures made of the pFe lines in the green, where they are conspicuous. On the assumption of a single series, displaced from 23 to 24 angstroms, towards violet, many other lines coincide with the stronger pTi lines given in Lockyer's tables. The pMg line 4481·6, recorded as a conspicuous line by Pickering in Nova Persei, is probably the line at 4460 on June 12 and 4458 on June 13.

The presence of many enhanced lines in the intermediate spectrum, and the strength of the ultra-violet continuous spectrum beyond the hydrogen series, in the bright-line stage, indicates relatively high temperature. My spectra are also extremely weak in the green in relation to Arcturus, but the two plates of the intermediate stage appear to be about equal in intensity to the Altair spectrum throughout the range photographed, that is from Hα to Hδ.

Concluding Remarks.

The most interesting result deduced from this series of spectra is the changing wave-lengths of the hydrogen lines and of the enhanced lines of iron, indicating increasing velocities of the dissipating gases. The analogy with the solar eruptive prominences which move with accelerating speed is striking; but the differences should also be emphasised. In the solar eruptions the enhanced lines of iron are confined to the chromosphere region, and are never seen high above the Sun's limb; also they never show the large displacements commonly displayed by the hydrogen and calcium lines; the iron vapour does not share in the rapid movements of the hydrogen and calcium. But in Nova Aquilæ the pFe lines give almost the same motion displacements as hydrogen and calcium, and the same acceleration.

Another difference is in the absorption effects. In the Sun, only the denser low-lying prominences give any indication of absorption when seen against the photospheric background, and this absorption is almost confined to the lines α and β. The chromosphere itself gives absorption lines diminishing in intensity from Hα to Hε, the rest of the series not appearing at all in the solar spectrum. In Nova Aquilæ, Hδ, ε, and ζ appear as the strongest absorption lines, the intensity diminishing both in the lines towards red and those towards the ultra-violet.

If we may designate the nova eruptions as "prominences," it is evidently necessary to modify our ideas derived from their solar analogues. In the first place, the nova prominences are not isolated streams of ejected gas, as in the sun, but vast masses moving outward in all directions from the central star. If the nova originally possessed a chromospheric envelope, this must have been thrown bodily outward, the moving masses subsequently coming under the influence of the intense light pressure, causing an acceleration of the motion (see note below).

The inference from the absorption phenomena is simply that the nova prominences must be both hotter and denser than the solar prominences.

Notwithstanding the differences mentioned, it seems probable that the forces concerned in the eruption, accelerating movement, and final dissipation of a solar prominence are also operating in novæ, and are largely concerned in the striking but very transient phenomena of the displaced absorption lines.

The measures of the widths of the emission bands after the bright-line stage was reached indicates that the widening is also a Doppler effect. If this is granted, the positions of the edges of $H\gamma$ and δ, which were not widened by over-exposure, indicate an approaching velocity of about 1660 km./sec. for the violet edges, and a receding velocity of 1500 km./sec. for the red edges of the bands, the centres being displaced to violet by an amount corresponding to a radial velocity of about −80 km./sec. The velocity with reference to the star itself would then be 1580 km./sec. This can scarcely be due to a rotation of the star, because in that case there would be a marked diminution of intensity towards the edges of the bands, whereas they have a nearly uniform background intensity from edge to edge, but with three brighter regions unsymmetrically superposed.

If the star in the later stages possesses no condensed opaque nucleus, but consists of a truly gaseous mass, mainly of hydrogen, and expanding uniformly in all directions with a velocity of 1580 km./sec., then the gas on the side towards Earth would not obstruct the radiation from the opposite side, because owing to the change of wave-length it would be transparent to the radiation from the receding gas. The result would be wide emission bands with edges defined by the velocity of the expansion. As the width of the bands is shown to be no indication of pressure, an exceedingly low pressure and low density may be assumed.

It is probably of significance that the lower limit of velocity given by the absorption lines is so near to the upper limit given by the emission bands; for it may be supposed that the absorbing hydrogen in the early stages also possessed this initial velocity of expansion, which was subsequently increased by light-pressure, or whatever the force may be which drives solar prominences outward into space.

Contrasting with these violent movements of hydrogen in the nova, the very tenuous calcium vapour giving the fine absorption lines H and K appears to be in a state of serene immobility, not with reference to Earth or Sun, but stationary in space with respect to the sidereal system.

Kodaikánal:
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Note added 1919 *April* 28.

Mr. Plaskett has pointed out to me that "the great range in the radial components of these outward rushing gases coming from one hemisphere of the star should make the lines very broad and indistinguishable, instead of, as they frequently are, sharp and narrow."

My reply to this is that the absorption lines may be supposed to be due to gases which have become separated from the main body, like solar eruptions, but on a vastly greater scale. It is easy to show that an outer shell of absorbing gas, separated from the star by a distance equal to the star's radius, would give absorption lines of such width that the minimum velocity indicated by the less refrangible edges would be 87 per cent. of the maximum, represented by the more refrangible edges. Gases moving out at angles greater than 30° to the line of sight would not occult any part of the star, and could not be seen by absorption. For velocities of 1600 and 2400 km./sec. the widths at Hγ would be 3 A. and 4·6 A. respectively, which is comparable with the actual widths of the hydrogen lines on June 13, although the metallic lines were narrower. The more refrangible line Hγ was, in fact, nearly twice the width indicated.

According to Mr. Plaskett's description of the spectral changes, it appears that both the hydrogen and the metallic lines were broader and more diffuse on June 10 than on later dates, which would indicate a smaller separation of the absorbing gases from the main body during the early stages.

Professor Newall considers the more refrangible series of hydrogen lines on June 13 to be blends, for each of the lines δ, γ, β on June 15 became two distinctly separated lines. This shows that two independent masses of hydrogen, moving with different velocities, were concerned in the widening on June 13.

It seems probable that only the gases of the star's original chromosphere lying outside the intensely luminous photosphere would be driven out in the way indicated if the repulsive force is light pressure.

TABLE I.

Spectrum of Nova Aquilæ.

June 12, 6h 30m G.M.T.		June 13, 6h 37m G.M.T.		Remarks.
λ.	I.	λ.	I.	
4071·9	10	4068	?	Hδ 2nd absorption line.
4080·2	8	4079·6	8	Hδ 1st absorption line.
4081 } 4119	...	4079 } 4118	...	Hδ emission band with maxima at about 4095 and 4105.
4141	6	4141	5	pTi 4163·8
4150	7	4150	6	} pFe 4179·0, also pTi 4172·0.
4156	5	4157	4	
		4159 } 4174 4191	...	Faint emission band visible also on the 12th but not measured. Maximum intensity 4174.
4192	2	...	...	Probably present, but very faint on 13th. ? pSr 4215·7.
4197	4			
4200	2	4199	2	
4203	1	4205	2	} pFe 4233·3.
4210	7	4211	8	
4224	3	4225	2	
		4227 } 4235	——	Emission band visible also on 12th.
4267	4	4269	3	pTi 4290·3.
4271	4	4272	2	pFe 4302·3, 4303·3. pTi 4294·2.
		4276	...	Apparent emission line on edge of absorption line.
4277	3	4278	3	pTi 4300·2.
4280	2	4279	2	Ill defined. pFe 4302·3, 4303·3.
4285	3	4286	0	pTi 4308·1.
4291	4	?		pTi 4313·0 and 4315·1.
4299	2	4299	0	
4303	2			
4308	7	4307	12	Hγ 2nd absorption line. The line at 4303 on the 12th is merged in Hγ absorption on the 13th.
4318	4	4319	5	Hγ 1st absorption line and pTi 4338·0.
4319		4320		V limit of emission band.
4328	2	4330	2	
4346	2	4346	2	Hγ emission band with many absorption lines superposed on it. Maximum intensity at 4332 to 4341. pFe and ? pTi lines.
4351	3	4351	1	
4361	3	4360	2	
4374	6	4373	5	
4376		4376	.	R limit of emission band.

TABLE I.—*continued.*

June 12, 6h 30m G.M.T. λ.	I.	June 13, 6h 37m G.M.T. λ.	I.	Remarks.
4380	2			
4384	0			
4396	2	4394	2	Broad line. ? pTi 4417·8.
4423	4	4421	3	Well defined. pTi 4443·9.
		4432	2	Ill defined.
4448	3	4446	4	pTi 4468·6.
4451	3	Absent.		
4456	1	Absent.		
4460	4	4458	2	pMg 4481·3.
4467	2	4464	1	Ill defined. pTi 4488·4.
4480	2	4478	2	} pFe 4508·4 and pTi 4501·4.
4487	0	4485	1	
4489	0	4490	1	} Group of lines pFe 4520·4, 522·7. Apparent emission band between 4500 and 4510.
4503	0	4498	1	
4513	2	4508	1	
4517	0	?		} pFe 4549·6 and pTi 4549·8
4527	3	4525	2	
4532	0	?		Traces only of these lines on June 13, pFe 4556·0.
4538	0	?		
4542	1	?		
4550	3	4548	3	pTi 4572·1.
Absent	...	4553	2	} pFe 4584·0.
4561	1	4557	2	
4563	0	Absent.		
?	...	4571	1	Wide lines very faintly indicated on June 12.
?	...	4579	1	
Absent	...	4586	2	
4595	2	4590	1	
·		4600	1	
4607	1	4610	3	Wide and diffuse.
Absent	...	4618	1	
?	...	4633	...	Emission band barely seen on June 12.
?	...	4650	...	Emission band barely seen on June 12. There is evidence of emission between all the absorption lines from 4500 to 4650.
4737	0	?		Traces of this faint group also visible on June 13.
4760	0			
4781	1	4784	0	pTi 4805·2.

TABLE I.—*continued.*

June 12, 6h [illegible]m G.M.T.		June 13, 6h 37m G.M.T.		Remarks.
λ.	I.	λ	I.	
4799	0			
4824	10	4822	15	Hβ 2nd absorption line, width 9 Å. on 13th.
4836	2	4836	1	Hβ 1st absorption line.
4835	...	4837	...	Hβ emission band, extends faintly from 4825 to 4898 in both spectra, maxima at about 4861.
4886		4886		
4888	4	4888	1	pFe 4924·1.
4899	8	4899	8	
4902	..	4901	...	Emission band, the densest part is from 4918 to 4930.
4919		4918		
4920		...		
4932		4930		
4934		4936		
4949		4949		
4983	8	4984	5	pFe 5018·6.
4993	8	4995	7	
4996	...	4997	...	Emission band with three regions of greater intensity.
5004		5002		
5013		5014		
5026		5028		
5030		5034		
5043		5048		
5133	8	5134	4	pFe 5169·2.
5144	8	5144	5	
5146	...	5148	...	Emission band with three regions of greater intensity.
5153		5156		
5165		5164		
5175		5178		
5186		5185		
5196		5194		

TABLE II.

Spectrum of Nova Aquilæ.

June 19, 5h 39m G.M.T.		June 20, 5h 50m G.M.T.		Remarks.
λ.	I.	λ.	I.	
3912	10?			Plate much under-exposed here.
3933	0			K. Very narrow line.
3947	15			Hε absorption.

TABLE II.—*continued.*

June 19, 5h 39m G.M.T.		June 20, 5h 50m G.M.T.		Remarks.
λ.	I.	λ.	I.	
3948 3968	0	?		H. Very narrow line superposed on Hε emission.
3979 3988	...	3979 3988	...	Brightest part of Hε emission on 20th.
4021 4052 4055	...	4025 4030 4055 4057	...	Faint emission band, strongest at 4052 to 4055 on 19th, and 4055 to 4057 on 20th.
4055 4067	8	4058 4069	8	Broad absorption band slightly marked maxima at 4057 and 4064 on 19th, 4060 and 4067 on 20th.
4077·9	10	4076·9 4078·3	4 6	Hδ absorption, double on 20th.
4079 4123	...	4079 4122	...	Hδ emission band with maxima at 4098, 4105, and 4118.
4208	1	?		
4210 4227 4256	0	4210 ? 4254		Faint emission band with undisplaced Ca absorption line superposed. pFe 4233.
4278	0	?		Broad and ill-defined line.
4315·4	8	4314·3 4315·7	2 4	Hγ absorption double on 20th.
4316 4363	...	4316 4363	...	Hγ emission with maxima at 4337, 4342, and 4356.
4375	0	4375 4377	1	Broad and ill-defined line, or space between emission bands.
4378 4424	..	4378 4424	...	Faint emission band, maxima at 4416.
4443 4474	...	4443 4474	...	Very faint emission band.
4504 4545	...	4500 4552	...	Faint emission band, limits very ill defined, pFe, several lines.
4555	1	Absent.		
4587 4592 4601	1 2 3	4589 4597 4604	1 2 3	Very broad and ill-defined lines.
4606 4719	...	4608 4705	...	Emission band with maxima at 4644. Intensity gradually reduced towards red.

TABLE II —*continued.*

June 19, 5h 33m G.M.T.		June 20, 5h 50m G.M.T.		Remarks.
λ	I.	λ.	I.	
4810 } 4823		4817		Faint absorption band.
		4831	2	Hβ absorption, more refrangible component of double.
4833 } 4887		4834 } 4886	...	Hβ emission, maxima at 4857, 4864, and 4882.
4895·1	1	?		Probably present, but very faint on 20th. pFe 4924.
4895 } 4950	...	4897 } 4947	...	Emission band very definitely bounded. pFe 4924.
4989·2	1	?	.	Probably present on 20th, but plate under-exposed. pFe 5018.
4990 } 5040	...	4992 } 5046	...	Emission band definitely bounded. pFe 5018.
5147 } 5200	...	5162 } 5197	...	Emission band, both plates much under-exposed here. pFe 5169.
(6563)		(6563)		Hα emission band well defined and similar to Hβ in structure.

TABLE III.

Spectrum of Nova Aquilæ.

July 6, 7h 20m G.M.T.		July 11, 4h 01m G.M.T.		Remarks
λ.	I.	λ.	I.	
3871	...		...	Hξ absorption line.
3872 } 3898 } 3912	3	3872 } 3898 } 3911	3	Hξ emission, trace of absorption line at 3898.
3950 } 3990	5	3948 } 3989	5	Hε emission, maxima at 3974 on 6th, 3973 and 3986 on 11th.
4005 } 4010	1	4004 } 4014	1	
4023 } 4030	2	4020 } 4029	0	He.
4034 } 4051	2	4038 } 4042	0	
4053 4064	...	4053 } 4060	3	Strong absorption band on 6th, emission band on 11th.
4066 } 4077	2	?		Probably present on 11th.

TABLE III.—*continued.*

July 6, 7^h 20^m G.M.T.		July 11, 4^h 01^m G.M.T.		Remarks.
λ.	I.	λ.	I.	
4079	...	4078	...	Hδ absorption line feebly indicated.
4080–4123	10	4075–4125	15	Hδ emission, maxima at 4105 on 6th, 4116 and 4360 on 11th.
4127–4142	1	Absent.		
4317–4363	15	4315–4366	20	Hγ emission, maxima at 4344 on 6th, 4343 and 4360 on 11th.
4373–4383	3	4378–4389	8	Neb. and He.
4407–4417	2	4396–4403	0	
4432–4435	0	4430–4440	1	
4446–4465	2	4446–4476	3	He?
4480–4488	2	4482–4496	2	
4508–4512	2			
4512–4548	3	4513–4532	1	
		4544–4552	0	
4583–4625	15	4606–4662	20	
4663–4690	4	4683–4704	4	Probably due to the chromosphere line 4686.
4834–4887	20	4832–4887	30	Hβ emission, maxima at 4863 on 6th, too dense on 11th to see details.
4899–4949	1	4930–4946	2	Neb. and He.
4949–4964	0	4946–4966	1	
4980–5030	2	4976–5033	8	Neb. and He., maximum at 4979 on 11th, uniform on 6th.

TABLE IV.

Hydrogen Emission Bands.

Hβ.

	Violet edge.	Red edge.	Centre.
June 18	4833·4	4886·7	4860·1
19	4833·2	4886·7	4860·0
20	4833·7	4886·6	4860·1
23	4833·7	4886·5	4860·1
July 6	4834·0	4886·8	4860·4
Means	4833·6	4886·7	4860·1
Mean width, and displacement of centre.	53·1 A.	1·4 A. = −86 km./sec.	

Hγ.

	Violet edge.	Red edge.	Centre.
June 18	4317	4362	4339·5
19	4316	4363	4339·5
20	4316	4363	4339·5
23	4317	4360	4338·5
July 6	4317	4363	4340·0
Means	4316·6	4362·2	4339·4
Mean width, and displacement of centre.	45·6 A.	1·2 A. = −83 km./sec.	

Hδ.

	Violet edge.	Red edge.	Centre.
June 18	4079	4122	4100·5
19	4079	4123	4101·0
20	4079	4122	4100·5
23	4079	4122	4100·5
July 6	4080	4123	4101·5
Means	4079·2	4122·4	4100·8
Mean width, and displacement of centre.	43·2 A.	1·1 A. = −81 km./sec.	