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THE SPECTRUM OF OMICRON CETI*

On account of the great instrumental power required for the observation of the spectra of faint objects, changes in the spectra of long-period variable stars have not been well studied. In fact there is no star which undergoes a large variation in brightness whose spectrum has been systematically followed from maximum to minimum, or vice versa. It is proposed to give here the results of a study of the spectrum of $\omicron$ Ceti, or Mira, made, at the suggestion of Director Campbell, with the thirty-six-inch refractor of the Lick Observatory, from June 1902 to January 1903. During this period the star faded in brightness from 3.8 to 9.0 magnitude. The first photograph of the spectrum was obtained about three weeks after the predicted time of maximum and a series of plates was secured, covering the interval to minimum. No negatives were obtained after the star had again begun to increase in brightness.

The most important articles concerning the spectrum of Mira are those of Vogel,[†] Sidgreaves,[‡] and Campbell § Neither Vogel nor Sidgreaves followed the star long enough to find much change in its spectrum, and Campbell's work was mainly in connection with observations of the star for radial velocity, with the Mills Spectrograph.

INSTRUMENTS AND METHODS.

The spectrograph used in my observations was the one employed by Messrs. Campbell and Wright in their work on Nova Persei, [L. O. Bulletin No. 8],

*Dissertation in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of California.

†H. C. Vogel. Ueber das Spectrum von Mira Ceti. Sitzungsberichte der Berlin Acad., 1896, p. 143.

‡Walter Sidgreaves. The Spectrum of $\omicron$ Ceti as Photographed at Stonyhurst College Observatory. Mon. Not. Roy. Astr. Soc., Vol. 58, p. 344, April 1898.

§ W. W. Campbell. Note on the Spectrum of $\omicron$ Ceti. Astrophysical Journal, Vol. IX, p. 31. Jan. 1899.

designated as "Spectrograph I." It is the regular Mills Spectrograph converted into a one-prism instrument. It gives good definition, on the same photograph, of the region from λ 3700 to λ 5600. The length of this range of spectrum is 28 millimeters. Although this dispersion is only about one-fifth of that of the three-prism instrument, it is enough to yield a very fair determination of velocity.

When the seeing is good, an exposure of ten minutes will give a satisfactory negative of a star to which the Draper Catalogue assigns the photographic magnitude 5.0. If $\omicron$ Ceti were of about the tenth photographic magnitude at minimum, it would require, roughly, an exposure one hundred times as long as a fifth magnitude star, or about sixteen hours. Some of the light being in bright lines, we should expect a still longer exposure to be necessary. This estimate agrees with my experience. About July 1, 1902, an hour's exposure, just before daylight, could be made on the star, and it was bright enough to photograph in that time. An exposure of six hours at the time of minimum, using the fastest photographic plate obtainable, was not sufficient to produce a measurable image, although much could be seen in a qualitative way. On January 5, 1903, the date of my last negative, an exposure of five hours, beginning soon after sunset, was possible. Early in March, 1903, the spectrum was again bright enough to record itself with a fairly short exposure; and in the absence of the writer, Messrs. Reese and Curtis were ready to make an attempt, but bad weather prevailed.

A Huggins reflecting slit is used with this instrument. A ninth magnitude star can be followed accurately.

No flexure of the instrument was noticed on any of the earlier plates. The comparison spectrum was inserted at least four times during each exposure, and

the definition was satisfactory. Several long exposures in September and October were imperfect, but the trouble was finally removed by taking greater precautions in tightening the various clamps and screws.

As there were no means of controlling electrically the temperature of the instrument, changes of temperature must have effected the definition. The spectrograph when in use was covered with two thicknesses of woolen blanket.

The same emulsion of Cramer's "Crown" plates was used for most of the work. A few exposures in July and August were made on Cramer's "Isochromatic Instantaneous," but the "Crown" plates were more sensitive.

All of the plates taken in this work were measured and reduced with the iron spark-spectrum as comparison. From the ultra-violet to λ 4415 there are many strong and sharp iron lines. From λ 4415 to

λ 5600 the iron lines are fainter, and many of them have companions. The region from λ 4800 to λ 5600 of the iron spectrum was photographed with three prisms. It was found that there were several lines in this region which had no companions, and which could be used without hesitation. Close double lines were assumed to have positions depending upon the relative intensities of their components.

The plates were measured with one of the measuring microscopes in use for the regular line of sight work. Each plate was measured with both violet left and violet right in the eye piece.

A plate of the sky was taken with a very long slit and the amount of the curvature of the comparison lines was determined in the same manner as by Campbell.* The curvature corrections were found to be insignificant.

* Astrophysical Journal, 1898, Vol. VIII, p. 144.

o CETI. 13E, 1902, July 16.				$\lambda = 2123.10 + \frac{332873}{220.653 - R}$			
Description.	Micrometer <i>R</i> .	$R_0 - R$	$\frac{1}{R_0 - R}$ 0.00	λ from Formula.	Correction to Formula.	Reduction to Sun.	λ
	20.706	199.947	500133	3787.91	+0.14		3788.05
	21.560	199.093	502278	3795.05	+0.10		3795.15
Bright, faint.	21.950	198.703	503264	3798.33	+0.10	+0.36	3798.79
	26.124	194.529	514062	3834.27	+0.09		3834.36
Bright.	26.301	194.352	514530	3835.83	+0.06	+0.36	3836.25
Bright, faint.	28.241	192.412	519718	3853.10	+0.05	+0.37	3853.52
	29.012	191.641	521809	3860.06	0.00		3860.06
	32.111	188.542	530386	3888.61	+0.06		3888.67
Bright.	32.208	188.445	530659	3889.52	+0.03	+0.37	3889.92
	32.870	187.783	532530	3895.75	+0.05		3895.80
	33.300	187.353	533752	3899.82	+0.03		3899.85
Bright, faint.	33.950	186.703	535610	3906.00	+0.02	+0.37	3906.39
	36.230	184.423	542232	3928.04	+0.04		3928.08
	40.364	180.289	554665	3969.43	-0.02		3969.41
H. line of sun.	40.345	180.308	554607	3969.24	0.00	+0.38	3969.62
Bright.	40.479	180.174	555019	3970.61	0.00	+0.38	3970.99
5 wide.	41.381	179.272	557812	3979.91	-0.01	+0.38	3980.28
5 wide.	41.665	178.988	558697	3982.85	-0.01	+0.38	3983.22
3	42.396	178.257	560988	3990.48	-0.01	+0.38	3990.85
Bright place.	43.116	177.537	563263	3998.05	-0.01	+0.38	3998.42
4	43.251	177.402	563692	3999.48	-0.01	+0.38	3999.85
Bright place.	43.518	177.135	564541	4002.30	-0.01	+0.38	4002.67
	43.810	176.843	565473	4005.41	0.00		4005.41
Bright place.	43.996	176.657	566069	4007.39	-0.02	+0.38	4007.75
4 wide.	44.170	176.483	566627	4009.25	-0.02	+0.38	4009.61
4	45.282	175.371	570220	4021.21	-0.02	+0.38	4021.57
5 very wide.	45.610	175.043	571288	4024.76	-0.02	+0.38	4025.12
4	45.850	174.803	572073	4027.38	-0.03	+0.38	4027.73
4 fine.	46.436	174.217	573997	4033.78	-0.03	+0.38	4034.13
	47.546	173.107	577677	4046.03	-0.05		4045.98
3	48.394	172.259	580521	4055.50	-0.03	+0.39	4055.86
	49.130	171.523	583012	4063.79	+0.15		4063.94
	49.849	170.804	585466	4071.96	-0.05		4071.91
4 wide.	50.414	170.239	587409	4078.43	-0.04	+0.39	4078.78
3 poor.	50.850	169.803	588918	4083.45	-0.04	+0.39	4083.80
3 poor.	51.274	169.379	590392	4088.36	-0.04	+0.39	4088.71
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

thing of interest was found on all other plates, except 57 A.

The brightness of the star at the time when each plate was taken is shown in Figure 1. The observations of visual magnitude are given at the end of this paper. As the plates are well distributed along the light curve until about the time of the minimum, no great change in the spectrum could have escaped observation.

ABSORPTION SPECTRUM.

As is well known, α Ceti and the other long-period variables have absorption spectra of Secchi's third type. Some observers have found the region from $H\gamma$ toward the red crossed by a series of dark bands, with edges sharp toward the violet, and they report that from $H\gamma$ to the ultra-violet the dark-line spectrum is very similar to that of the sun. At first glance this seems to be verified by my plates, but a closer study shows the details to be very different. Figure 2 shows an eight-fold enlargement of the solar spectrum, photographed with Spectrograph I on a lantern-slide plate. The absorption spectrum of the star, Figures 3 to 6, is seen to resemble little that of the sun. The date of Figure 4 should be August 11, instead of August 4, as is printed.

In comparing the star spectrum with the solar spectrum, it was not found best simply to measure the plates and then look for coincidences in Rowland's table. It is easy to find a line in the table which agrees in position with the one on the plate, but the intensities may be very different. The method adopted was to compare a plate of α Ceti with one of the sky. The two negatives, film sides together, were examined under the microscope with a low power.

The strong calcium lines g , H , and K , are present in the spectrum of the star, the g line being much more intense than in the solar spectrum. The strong iron lines of the sun are not so prominent in α Ceti; in fact they do not show with low dispersion. Of the large number of lines in the star spectrum, there are very few which coincide with lines of like intensity in the solar spectrum.

The absorption spectrum of Mira was measured accurately on seven plates. Each plate was measured and reduced independently, so that a faint line might be measured on one plate without being noticed on any of the others. This does not mean that it had developed, or that its intensity had changed. Such lines, of which many were measured, could be easily obscured by an irregular arrangement of the silver grains. The best method of verifying changes is to examine different plates simultaneously, in pairs, under the microscope. This has been done, and all changes in intensity or character have been noted.

In TABLE II are given the wave-lengths of the absorption spectrum as derived from all the measures. The numbers expressing the intensity indicate, in a general way, the relative strength of the lines. It was intended, on each plate, to assign intensity 1 to the faintest lines distinguishable, and intensity 10 to the strong line at $\lambda 4255$. On this scale the g , H , and K lines might be 100 or 500, it matters little. The intensities assigned are merely relative, and no doubt the scale varies much in different parts of the spectrum. The lines on each plate were assigned intensities when the plate was measured; and when the different results were brought together, a sort of mean of the estimates was taken for each line. Where the estimates did not agree well, the line was compared directly on two or more plates to see if any change had taken place.

The residuals in the table were formed by subtracting the mean wave-lengths from the values given by each plate. All plates were assigned equal weight in forming the means. Periods (. . .) signify that when the plate was measured nothing was noticed in the spectrum at that place. A dash (—) denotes that the line was observed but could not be measured accurately. When a line was measured on only one plate there is no residual, and the dash indicates the plate referred to.

Plate 18F was measured only from $\lambda 4300$ toward the red. The comparison on 7 C being underexposed to the red of $\lambda 4415$, the plate was not measured in that region.

TABLE II.—ABSORPTION SPECTRUM OF α CETI.

Intensity.	Observed λ	Residuals in 0.01 m.							REMARKS.
		7C	13E	18F	25F	27D	28D	2235D	
	3936.—					—	—		{ K line of sun, very strong. Adjacent bright lines interfere with measurement of λ .
5 wide	3945.09	04	....	....	....	01	02	....	
5 wide	3949.28	14	....	....	....	—	14	....	
2 fine	3951.65	....	....	....	....	....	—	....	
2	3957.27	....	....	....	....	....	—	....	
4	3958.98	—				03	03		{ H line of sun, very strong. Adjacent bright lines interfere with measurement of λ .
5 wide	3962.55	—	....	....	....	00	00	....	
	3969.6—	—	—	....	....	....	—	....	
4 wide	3980.20	....	08	....	....	....	09	....	
5 wide	3983.18	10	04	....	19	01	05	....	
5	3990.64		21		24	04	07		
2 fine	3997.61	—							
4	3999.72	09	13		02	07	22	11	

2

3

4

5

6

2. SOLAR SPECTRUM (SKY).

3. o CETI, 1902 July 6. 7 C.

4. o CETI, 1902 August 4. 27 D.

5. o CETI, 1902 September 6. 33 D.

6. o CETI, 1902 October 4. 42 A.

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TABLE II.—ABSORPTION OF SPECTRUM OF α CETI.—(Continued.)

Intensity.	Observed λ	Residuals in 0.01 m.							REMARKS.
		7C	13E	18F	25F	27D	28D	2235D	
4 wide	4005.6—	....	....	....	—	....	....	....	Perhaps several.
5 wide	4009.63	....	02	....	05	17	....	20	Perhaps several.
4	4010.04	....	....	....	....	....	—	....	
3	4012.18	....	....	....	15	....	23	09	
1	4018.91	....	....	....	....	....	—	....	
4 wide	4021.41	14	16	....	00	08	10	04	
5 wide	4025.08	17	04	....	17	08	03	14	
3 wide	4027.68	20	05	....	10	....	09	26	
2 wide	4030.16	....	....	....	03	....	04	....	
6	4032.22	19	....	....	15	05	38	27	
7	4034.04	05	09	....	01	02	03	11	
1 fine	4035.71	....	....	....	—	....	....	....	
2	4036.22	....	....	....	....	....	—	....	
3	4045.16	....	....	....	03	02	....	....	
2 fine	4047.02	—	....	....	....	....	....	....	
	4043.—	....	....	....	—	—	....	—	} Several lines run together.
	4050.—	....	....	....	—	—	....	—	
3	4053.25	....	....	....	....	....	....	—	
6	4055.71	....	15	....	01	09	19	12	
2	4058.14	....	....	....	12	....	....	11	
2 wide	4060.43	....	....	....	03	....	....	03	
	4064.—	....	....	....	....	—	—	....	Too wide and faint to measure. Probably several.
4 wide	4068.24	....	....	....	....	....	....	—	
	4072.—	....	....	....	....	—	—	....	Too wide and faint to measure. Probably several.
5 wide	4072.28	....	....	....	09	01	....	09	
2 fine	4077.24	—	—	....	08	11	02	—	} On plates 7C, 13E and 2235D these two lines run together.
7 wide	4079.51	—	—	....	02	04	03	—	
4 wide	4083.85	15	05	....	12	36	06	39	
3	4088.88	20	17	....	07	11	04	05	
1 fine	4091.33	....	—	....	....	....	....	....	
5	4093.55	....	18	....	00	12	21	13	
3	4097.08	....	....	....	01	13	08	04	
3 fine	4100.56	....	....	....	....	....	—	....	
4	4105.88	....	....	....	07	....	....	08	
5	4110.34	....	07	....	09	....	08	09	
5	4112.97	....	07	....	07	....	....	....	
4 fine	4116.14	....	....	....	....	....	....	—	
4 fine	4117.71	....	00	....	15	....	18	01	
	4117.9—	....	....	....	....	....	—	....	} Several.
	4119.1—	....	....	....	....	....	—	....	
4 fine	4121.44	....	....	....	....	....	....	—	
4 fine	4122.62	....	....	....	....	....	....	—	
6	4124.66	01	21	....	15	....	02	06	
2 fine	4126.99	....	....	....	....	....	—	....	
3	4129.04	....	....	....	—	....	....	....	
3	4130.60	....	....	....	04	05	....	....	
4 fine	4133.00	....	....	....	....	....	—	....	
5	4135.32	17	05	....	12	10	17	15	
3	4137.77	11	....	....	....	....	....	11	
2	4140.96	....	....	....	00	....	....	01	
4 wide	4144.—	—	....	....	—	—	....	—	
3	4150.73	....	....	....	12	....	....	12	
3	4153.40	....	04	....	01	....	....	04	
3	4156.78	....	12	....	....	....	....	11	
4	4160.89	....	....	....	....	....	....	—	
3	4165.82	....	....	....	....	....	....	—	Poor.
3	4169.27	....	....	....	17	....	00	18	
3	4173.56	....	—	....	....	....	....	....	
7	4175.41	11	28	....	01	03	23	05	
4	4178.32	10	13	....	07	16	23	04	
2	4180.96	....	....	....	....	08	07	....	
3	4183.73	....	....	....	—	....	....	....	

TABLE II.—ABSORPTION OF SPECTRUM OF *o* CETI.—(Continued.)

Intensity.	Observed λ	Residuals in 0.01 μ m.							REMARKS.
		7C	13E	18F	25F	27D	28D	2235D	
4 wide	4188.17	....	....	....	16	14	23	26	
5 wide	4191.79	01	08	....	07	08	36	32	
3	4199.79	....	....	....	....	....	....	—	
2 wide	4211.19	....	....	....	27	27	....	....	Poor.
4 wide	4214.86	....	....	....	12	....	11	....	
	4227.84	00	28	....	—	10	18	—	<i>g</i> line of sun, very strong.
5	4235.37	....	10	....	04	....	07	....	
3	4242.82	....	....	....	03	....	....	04	
3	4251.60	....	02	....	11	....	....	10	
10	4255.46	06	33	....	08	26	06	01	
1	4259.64	....	....	....	—	....	....	....	
1 wide	4261.87	....	....	....	—	....	....	....	Poor.
4	4273.15	....	02	....	00	....	....	02	
8	4275.84	00	17	....	06	03	04	06	
5	4285.28	....	—	....	....	....	....	....	
6	4290.72	22	....	....	13	03	11	17	
2 fine	4292.45	—	....	....	....	....	....	....	
1	4295.07	....	....	....	....	....	....	—	
2 fine	4297.56	....	....	....	....	....	....	—	
3	4300.16	06	....	....	....	....	....	06	
2	4304.06	....	—	....	....	....	....	....	
3	4307.23	02	12	....	....	....	....	15	
3	4310.57	....	07	....	....	....	....	06	
	4314.29	....	....	00	00	....	01	00	Head.
2 fine	4320.03	—	....	....	....	....	....	....	
3	4326.97	06	....	....	10	....	....	05	
2	4331.13	....	....	....	—	....	....	....	
2	4348.12	....	....	....	—	....	....	....	
	4353.60	....	18	08	06	—	—	18	Head.
4	4380.31	03	....	....	06	....	25	35	
5	4385.49	12	09	....	04	14	09	02	
4	4390.71	22	02	....	14	11	25	24	
	4395.89	24	....	24	13	—	—	36	Head.
Residuals in 0.1 μ m.									
	4422.4	..	2	1	1	1	0	1	Head.
4	4461.1	..	..	..	—	..	..	..	
	4463.0	..	4	1	2	3	4	0	Head.
	4505.7	..	0	1	2	..	..	1	Head.
4 wide	4514.7	..	..	..	..	—	..	..	
3 wide	4519.8	..	..	..	..	—	..	..	
2	4530.7	..	..	..	—	..	..	..	
4	4536.8	..	2	3	1	..	5	..	
	4548.8	..	4	2	4	..	..	6	Head.
	4585.0	..	2	1	3	4	3	3	Head.
	4626.8	..	1	4	2	6	2	0	Head.
	4669.6	..	1	3	5	3	[21]	6	Head. Measure* of Plate 28D rejected for discordance.
5	4709.2	..	2	0	..	1	..	3	
	4714.2	..	4	3	1	..	..	..	Head.
10	4739.5	..	1	2	3	1	3	4	
	4760.0	..	2	4	3	4	6	5	Head.
	4804.2	..	0	4	3	0	5	1	Head.
	4842.8	..	..	..	..	2	2	..	Head.
	4954.1	..	2	3	3	4	0	0	Head.
	5167.0	..	2	8	2	..	..	5	Head.
	5308.3	..	—	..	..	..	..	..	Head.
	5358.8	..	—	..	..	..	..	..	Head.
	5439.4	..	—	..	..	..	..	..	Head.
	5447.9	..	2	0	7	..	..	5	Head.
	5498.0	..	—	..	..	..	..	..	Head.
	5568.7	..	..	..	..	..	..	—	Head.

From the residuals in TABLE II it is found that the probable error of the wave-length of a dark line derived from one plate is ± 0.10 tenthmeters. When a line was measured on six plates the probable error of its mean position is therefore ± 0.04 tm. In computing the probable error, the residuals from all lines to the violet of $\lambda 4400$ were used.

Many of the lines being broad or unsymmetrical and difficult to measure, the residuals from different plates are not larger than would be expected. While the agreement of the results with each other is not a test as to systematic errors, yet I feel sure that the wave-lengths of but few of the dark lines measured on several plates can be in error by as much as 0.2 tm.

A glance at the residuals shows that there is no evidence of variable velocity in the line of sight. Those from Mr. Wright's plate No. 2235 D, which was taken in 1901, indicate that the velocity was about the same during the corresponding phase of the star's light curve, a year previous. The residuals for each plate have been averaged; and if there were any change in the velocity it would appear in the mean residuals. The arithmetical means of the residuals to the violet of $\lambda 4400$, and the corresponding velocities in kilometers per second, are as follows:

Date.	Plate No.	tm.	km.
1902 July 6	7 C	+0.02	+1
16	13 E	+0.06	+4
Aug. 4	25 F	-0.03	-2
11	27 D	-0.02	-1
25	28 D	-0.03	-2
1901 Aug. 17	2235 D	+0.02	+1

Since many of the lines were not measured on all of these plates, the average residual of one plate is

not strictly the average deviation of the measures on that plate from the mean of all the plates, but no sensible error is introduced by this assumption. When it is remembered that all lines, good and poor, were included in the means, and that these plates were taken with a one-prism instrument giving a dispersion of but one-fifth of that of the regular Mills Spectrograph, the range of only 6 km. on six plates is very satisfactory. None of the plates taken later in 1902 are good enough to afford comparable conclusions as to the velocity; and it was thought best to measure only first class plates in this connection.

The result that the star's velocity was constant over a certain period was derived without assuming the coincidence of any of the star lines with lines of the solar spectrum, or with other known lines. A determination of the actual radial velocity requires an assumption as to what the wave-lengths of the star lines would be if they were not affected by velocity. Agreements of star and solar lines were looked for, by direct comparison of the star plates with a solar plate, and the only coincidences which seem certain are given in Table III. The wave-lengths and other data of the solar lines are from Rowland's table.

The *H* and *K* lines could not be measured accurately; the double manganese line at $\lambda 4030.92$ gives a discordant result, which was rejected, and it looks as though both a strontium and a titanium line make up a stellar line at $\lambda 4079.51$. The velocity of $+66^{\text{km}}$ was therefore derived from measures of only six lines, and none of these are fine and sharp enough to give the best determination.

TABLE III.—COINCIDENCES OF DARK LINES IN THE SPECTRA OF α CETI AND THE SUN.

α Ceti.		Sun.	Displacement.	Velocity.	Sun.
Intensity and Character.	λ	λ	tm.	km.	Substance and Intensity.
Strong	3936.—	33.82	—	—	Ca 1000 (<i>K</i>)
5 wide	3945.09	44.16	+0.93	+71	Al 15
5 wide	3962.55	61.67	+0.88	+67	Al 20
Strong	3969.6—	68.62	—	—	Ca 700 (<i>H</i>)
6	4032.22	30.92	[+1.30]	[+96]	Mn 4 and 5
7	4034.04	33.22	+0.82	+61	Fe-Mn 7
7 wide	4079.51	77.88	—	—	Sr 8
		78.63	—	—	Ti 3
Strong	4227.84	26.90	+0.94	+67	Ca 20 (<i>g</i>)
10	4255.46	54.50	+0.96	+68	Cr 8
8	4275.84	74.96	+0.88	+62	Cr 7

Mean $+66^{\text{km}}$

Campbell in 1898 found $+62^{\text{km}}$ with the three-prism instrument. The interval between August 29, 1898, the date of his first plate that year, to August 25, 1902, is equal to 130 days more than four periods of 331 days. The radial velocity has therefore been observed to be constant over about two-fifths of the period of light change.

To determine more coincidences, I have measured

one of the high dispersion plates of α Ceti, taken by Dr. Campbell in 1897. Although the plate is underexposed, about seventy lines were measured between $\lambda 4300$ and $\lambda 4420$, and more than twenty coincidences were found by direct comparison with a solar plate. The results are given in Table IV. As was done for the one-prism plates, the intensities are expressed on an arbitrary scale of 10.

TABLE IV.—ABSORPTION SPECTRUM OF α CETI. HIGH DISPERSION. PLATE 576B. 1897 DECEMBER 15.

α Ceti.	Sun.	Displacement.	Velocity.	REMARKS.		
Intensity and Character.	λ	λ	tm.	km.		
Several	{ 4299.7-	.....	.....	.....	} Narrower in $\odot$.	
	{ 4300.8-	.....	.....	.....		
3	4301.58	.....	.....	.....	} Closer double in $\odot$.	
3	4302.17	.....	.....	.....		
2	4303.56	02.69	+0.87	+60.6	Ca 4.	
5, double ?	4307.10	.....	.....	.....	Not $\odot$.	
3	4308.16	.....	.....	.....	Not $\odot$.	
4	4308.94	—	—	—	07.91 Ca 3, 08.08 Fe 6.	
4	4310.83	.....	.....	.....	Not $\odot$.	
1	4312.90	.....	.....	.....	Not $\odot$.	
Several	{ 4315.2-	.....	.....	.....	} Not $\odot$.	
	{ 4316.1-	.....	.....	.....		
2	4319.77	18.82	+0.95	+65.9	Ca, Mn ? 4.	
Bright place	4325.93	.....	.....	.....	Same in $\odot$.	
6	4326.85	25.94	+0.91	+63.0	Fe 8.	
1	4327.96	.....	.....	.....	Not $\odot$.	
1	4328.69	.....	.....	.....	Not $\odot$.	
1	4329.53	.....	.....	.....	Not $\odot$.	
1	4330.30	.....	.....	.....	Not $\odot$.	
5	4331.13	30.19	+0.94	+65.0	V 0 } Stronger than in $\odot$.	
5	4333.92	32.99	+0.93	+64.4	V 0 }	
Several	{ 4334.68	.....	.....	.....	} Not $\odot$.	
	{ 4335.29	.....	.....	.....		
Poor { 2	4335.91	.....	.....	.....	} Possibly weak lines in $\odot$.	
1	4336.38	.....	.....	.....		
1	4337.07	.....	.....	.....	Not $\odot$.	
2	4338.16	37.22	+0.94	+65.0	Fe 5.	
2	4338.61	37.72	+0.89	+61.5	Cr 3.	
1	4339.11	.....	.....	.....	Not $\odot$.	
3	4345.56	44.67	+0.89	+61.4	Cr 4.	
4	4348.27	.....	.....	.....	Not $\odot$.	
1	4352.16	51.22	+0.94	+64.8	Cr 3.	
Poor 2	4352.90	51.93	+0.97	+66.8	Cr 3.	
Head of band	4353.7-	.....	.....	.....	Not $\odot$. Mean of 4 plates with one prism 4353.6.	
5	4353.91	52.91	[+1.00]	[+68.9]	Fe 4. This line always gives + residual in other stars.	
3	4356.97	.....	.....	.....	Perhaps $\odot$, not certain.	
1	4359.70	.....	.....	.....	} All weak lines in star. No coincidences certain.	
1	4360.12	.....	.....	.....		
1	4360.65	.....	.....	.....		
1	4361.73	.....	.....	.....		
Poor 1 wide	4363.05	.....	.....	.....		
2	4365.56	.....	.....	.....		
2	4367.10	.....	.....	.....		
1	4367.87	.....	.....	.....		
4	4369.07					Not $\odot$.
1	4370.48					Not $\odot$.
1	4371.23	.....	.....	.....	Not $\odot$.	
4	4372.22	—	—	—	(71.14 Zr 1, 71.22 -1, 71.44 Cr 4) same appearance.	
1	4373.17	.....	.....	.....	Not $\odot$.	
Several to violet of	4376.4-	.....	.....	.....	Different in $\odot$.	

TABLE IV.—ABSORPTION SPECTRUM OF *o* CETI. HIGH DISPERSION. PLATE 576B. 1897 DECEMBER 15.—(Continued.)

1903Lick

o Ceti.		Sun.	Displacement.	Velocity.	REMARKS.
Intensity and Character.	λ	λ	tm.	km.	
Bright place	4376.68	.....	.....	.....	Not $\odot$. This develops into a bright line.
5	4377.06	76.11	+0.95	+65.1	Fe 6.
1 wide	4378.06	.....	.....	.....	} Different in $\odot$.
1 wide	4379.17	.....	.....	.....	
10	4380.27	79.40	+0.87	+59.5	V 4.
1	4383.67	.....	.....	.....	Not $\odot$.
6	4384.62	83.72	+0.90	+61.6	Fe 15.
7 double?	4385.90	.....	.....	.....	84.87 V 3, 85.14 Cr 2.
5	4390.26	89.41	+0.85	+58.1	Fe 2.
4	4391.06	90.15	+0.91	+62.2	V 2.
Poor 2 wide	4392.76	91.92	+0.84	+57.4	Cr 1.
7	4396.20	.....	.....	.....	} Stronger in star than in $\odot$.
2	4401.61	00.74	+0.87	+59.2	
10 wide	4405.89	04.93	+0.96	+65.3	95.20 Ti 3, 95.41 V 2.
2	4407.02	.....	.....	.....	V 1.
4	4407.72	06.81	+0.91	+61.9	Fe 10.
4	4408.70	.....	.....	.....	Not $\odot$.
10	4409.41	.....	.....	.....	V 2.
Several to violet of	4416.7-	.....	.....	.....	07.81 V 2, 07.87 Fe 4.
4	4417.59	16.64	+0.95	+64.4	08.36 V 2, 08.58 Fe 3, 08.68 V 2.
Head of band	4422.5-	.....	.....	.....	Different in $\odot$.
					V 0. Stronger in star than in $\odot$.
					Not $\odot$. Mean of 6 plates with 1 prism, 4422.4.
Mean of 20 lines +62.7 ^{km}					

A comparison of Table IV with the corresponding part of Table II is a test of the reliability of the results obtained with one prism.

One Prism.		Three Prisms.	
Description.	λ	λ	Description.
3	4300.16	{ 99.7-	} Several.
2	4304.06	{ 00.8-	
3	4307.23	.....	Not measured
3	4310.57	07.10	5
Head	4314.29	10.83	4
2	4320.03	.....	Not measured
3	4326.97	19.77	2
2	4331.13	26.85	6
2	4348.12	31.13	5
Head	4353.6-	48.27	4
4	4380.31	53.7-	Head
5	4385.49	80.27	10
4	4390.71	{ 84.62	6
Head	4395.89	{ 85.90	7
Head	4422.4-	{ 90.26	5
		{ 91.06	4
		.....	Not measured
		22.5-	Head

As might have been expected, many lines observed as single with one prism are really made up of two or more components. This comparison also shows that the wave-lengths of Table II are probably not quite so accurate as the residuals indicate.

A brief summary of the number of dark lines of different elements observed in the spectrum may be of interest.

Element.	No. of lines.
Ca	6
Fe	11
Cr	9
V	11
Al	2
Sr	1
Mn	3
Ti	2
	} ?

There can be no doubt of the presence of the first four elements in the list, and the aluminum and strontium lines are prominent; but manganese and titanium must be considered as doubtful.

On account of the varying instrumental conditions it is easy to fall into error in judging as to changes in the intensity and character of dark lines. If all the negatives were of the same density and of uniform excellence, it would be easy to note such changes. There is one dark line which showed changes of which the reality is certain. This is the *g* calcium line at λ 4227.84. Figures 3 to 5 show how it broadened as the star grew faint. Measures of its width are necessarily rough, and must depend much upon the judgment of the observer. The measures of two plates are as follows:

Date.	Plate.	Width.
1902 June 27	2 B	2 tm.
September 6	33 D	9 tm.

Other plates taken between these dates gave intermediate values. The intensity of continuous spectrum, in the neighborhood of λ 4227, is almost the same on plates 2 B and 33 D.

The general impression formed from examining the series of plates is that many other lines also grew broader as the brightness declined, but this is not certain. The effects of greater width of the slit, reduced intensity of the resulting negative, and flexure and temperature changes resulting from longer exposure, would all tend to make the lines wider and less sharply defined. The *H* and *K* lines are not shown

on most of the plates, and nothing can be said as to changes in their character.

A few lines not visible on the early plates became prominent later. Four such lines have the following positions:

λ 3990.64
4045.16
4093.55
4097.08

Lines of the solar spectrum which certainly coincide with these have not been found. The residuals in TABLE II indicate when these lines first appeared.

BANDS.

The prominent bands in the spectrum of Mira have been considered by some observers as a series of dark bands, with sharp edges toward the violet, and shading off toward the red. Others think them to be bright flutings like those of the arc spectrum of carbon. For convenience, they will be considered, in this paper, as dark absorption bands. On the plates of α Ceti and other third-type stars taken with Spectrograph I, the bright portions of the banded spectrum are certainly brighter relative to the region above $H\gamma$, where there are no bands, than are the corresponding portions of the spectrum of a solar-type star. However, the dark portions are fainter than the same places in the solar type of spectrum.

In measuring the plates the micrometer wire was set on the division between a dark and a bright portion of the spectrum, so that the measurements remain the same whether the bands be considered as bright or dark. While the line of separation is probably sharp in most cases, its exact position is not easy to determine. No doubt the effect of irradiation plays an important part in direct visual observations. Since the bands considered as bright have their sharp edges toward the red, the effect of irradiation would be to make the observed wave-lengths of the heads too large. Corresponding to this visual error is the effect of spreading of the image on a photographic plate, causing an error in the same direction, and a slight allowance was made for it in executing the measures. At my request, Dr. Reese made several settings on the head of a band. The difference between his measures and mine was 0.3 m., my estimate being that much farther to the red. Although this was the only comparison made with another observer, it seems highly improbable that two persons should disagree by as much as one tenth-meter in the measurement of a sharply defined head.

No attempt was made to determine the position of the more diffuse ends of the bands. In many cases the intensity changes gradually from head to head, there being heavy absorption at the sharp edge, the

spectrum growing uniformly brighter to the next line of demarcation.

Sidgreaves, on comparing the spectrum of α Ceti with that of α Herculis and other third-type stars, found a difference in the wave-length of the same band in different stars. For the head at λ 5447 in α Ceti, he found the position of λ 5458 in α Herculis, and intermediate values for α Orionis and β Pegasi. He suspected these discrepancies to be due to instrumental causes, but of this he was not certain. His work being done with an objective prism, he had no comparison spectrum with which to test the reality of the observed differences.

Along with the work on α Ceti in 1902, plates were taken of α Herculis, β Pegasi, ρ Persei, α Ceti and α Orionis. As these stars are all bright, the exposures on them were comparatively short, from five minutes to one hour. Isochromatic plates were used, so that a range of spectrum as far to the red as λ 5600 was covered. They were measured only for the positions of the heads of the bands. In the spectrum of Mira there are few dark lines shown in the region of the bands, but in the others many lines were recorded. Where there are more lines the bands are less prominent, and in the case of α Ceti and α Orionis, only three bands could be measured. All of these stars are on the regular Mills Spectrograph program, and their radial velocities have been determined from their dark line spectra in the region of $H\gamma$. As the wave-lengths of the bands must be affected by the radial velocities, it is necessary to apply to each observed wave-length a corresponding correction. In TABLE V is given, first the observed wave-lengths of the head of each band, already corrected for the orbital motion of the earth. The accompanying correction is that which must be applied to each wave-length in order to reduce it to what it would be if the star's radial velocity referred to the sun were zero. The mean result from the five stars has been taken after applying these corrections.

All bands visible on the plates were measured; and if the position of a band is not given for a star, it was not apparent. The results for any star are from all the plates of that star, except in the case of α Herculis, where one of the plates was a "Crown" plate and showed nothing to the red of λ 4954.

The results obtained by Sidgreaves, Vogel and others are inserted for comparison. The corrections given by Sidgreaves in Mon. Not., Vol. 59, p. 509, have been applied to his first published wave-lengths. Vogel's photographs did not extend to the red of λ 4800. The results of visual observations of the bands in third-type stars are taken from Frost's Scheiner.

TABLE V.—MEASURES OF BANDS.

α Ceti. Several Plates. +62km.	α Herculis. 2 and 1 Plate. -34km.	ρ Persei. 2 Plates. +27km.	β Pegasi. 2 Plates. +8km.	α Orionis. 4 Plates. +18km.	α Ceti. 2 Plates. -25km.	Corrected Mean. Excluding α Ceti.	α Ceti Corrected for +62km.	Sidgreaves. α Ceti.	Vogel. α Ceti.	Vogel and others. 3rd type stars. Visual.
4314.3 -0.9	.....	.....	.....	.....	.....	.....	4313.4	.....	.....	.....
4353.6 -0.9	.....	.....	.....	.....	.....	.....	4352.7	4352	.....	.....
4395.9 -0.9	.....	.....	.....	.....	.....	.....	4395.0	4395	.....	.....
4422.4 -0.9	4421.0 ± 0.5	.....	.....	.....	.....	4421.5	4421.5	4421	4422	.....
4463.0 -0.9	.....	.....	.....	.....	.....	.....	4462.1	4460	4462	.....
4505.7 -0.9	.....	.....	.....	.....	.....	.....	4504.8	4504	4506	.....
4548.8 -0.9	.....	.....	.....	.....	.....	.....	4547.9	4546	4545	.....
4585.0 -0.9	4583.9 ± 0.5	4584.8 -0.4	.....	.....	.....	4584.4	4584.1	4583	4581	4608
4626.8 -1.0	4625.7 ± 0.5	4626.8 -0.4	.....	.....	.....	4626.3	4625.8	4625	4622	.....
4669.6 -1.0	4667.1 ± 0.5	4667.9 -0.4	.....	.....	.....	4667.6	4668.6	4669	4666	.....
4714.2 -1.0	4713.6 ± 0.5	.....	.....	.....	.....	4714.1	4713.2	4714	4710	.....
.....	4736.6 ± 0.5	.....	.....	.....	.....	4737.1	.....	4736	.....	.....
4760.0 -1.0	4760.0 ± 0.5	4761.3 -0.4	4761.8 -0.1	.....	.....	4761.0	4759.0	4758	4755	4767
4804.2 -1.0	4803.5 ± 0.5	4804.9 -0.4	4805.4 -0.1	.....	.....	4804.6	4803.2	4803	.....	.....
4842.8 -1.0	.....	.....	.....	.....	.....	.....	4841.8	4842	.....	.....
.....	.....	4848.8 -0.4	.....	.....	.....	4848.4	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	4892	.....	.....
4954.1 -1.0	4953.0 ± 0.6	4954.7 -0.4	4954.6 -0.1	4955.4 -0.3	4954.7 ± 0.4	4954.5	4953.1	4951	.....	4960
.....	.....	.....	.....	.....	.....	.....	.....	4998	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	5046	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	5074	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	5098	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	5135	.....	.....
5167.0 -1.1	5165.0 ± 0.6	5166.6 -0.5	5166.3 -0.1	5165.8 -0.3	5165.4 ± 0.4	5165.8	5165.9	5162	.....	5169
.....	.....	.....	.....	.....	.....	.....	.....	5237	.....	5244
5308.3 -1.1	.....	.....	.....	.....	.....	.....	5307.2	5306	.....	.....
5358.8 -1.1	.....	.....	.....	.....	.....	.....	5357.7	5356	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	5406	.....	.....
5439.4 -1.1	.....	.....	.....	.....	.....	.....	5438.3	.....	.....	.....
5447.9 -1.1	5446.9 ± 0.6	5447.9 -0.5	5446.7 -0.2	5446.3 -0.3	5445.9 ± 0.5	5446.8	5446.8	5447	.....	5453
5498.0 -1.1	5496.5 ± 0.6	5497.1 -0.5	.....	.....	.....	5496.8	5496.9	5498	.....	.....

Several objects measured as bands by the writer were not recorded by Sidgreaves; but they are not prominent, and we should not expect different observers with different instruments to agree as to details. Sidgreaves recorded more bands than I did to the red of $\lambda 4954$. The plates taken with Spectrograph I are underexposed in this region and only the more prominent bands show.

A comparison of the corrected positions for α Ceti with the means for the other stars shows that there is little difference in the wave-lengths, except that due to different radial velocities.

It is interesting to note what effect the application of the corrections for radial velocities has upon the agreement of the results. Residuals have been formed by subtracting the mean positions from those of each of the five stars. The sum of the squares of the residuals is reduced from 12.34 to 5.46 by the application of the corrections. This diminution of the residuals shows the validity of the assumption that the positions of the bands are the same in the five stars observed, and that the bands in each star have the same displacement, due to velocity, as have the fine, dark lines in the $H\gamma$ region.

However, the case is not clear with α Ceti. The correction for +62km changes the sum of the squares of the residuals, obtained by subtracting the mean wave-lengths of the other stars from those of the α Ceti, from 10.84 to 10.09. The corrections change the algebraic sum of the residuals from +5.8 m. to -5.3 m. This result is not surprising when it is remembered that all poorly defined bands were included in forming the residuals.

Judging by the accordance of the individual results and allowing for any chance of personal error in the measures, it seems unlikely that the position of a sharply defined head of band should be in error by as much as one tenth-meter.

As far as I know, the identification of the bands of the third type stars has not been accomplished. If the division at $\lambda 5165.9$ be considered as the head of a bright band, it is in close agreement with the head of the third carbon band at $\lambda 5165.3$, as measured by Kayser and Runge. The head at $\lambda 4737.1$, measured in α Herculis, may also correspond to their fourth carbon band, $\lambda 4737.2$. These two coincidences are the only ones I have found and we certainly need more evidence before drawing any conclusions from them.

VARIATIONS OF INTENSITY IN THE CONTINUOUS SPECTRUM.

Sidgreaves found that the continuous part of some regions of the star's spectrum changed in relative intensity as the star grew fainter. These changes have been verified in the present work.

In order to estimate the relative brightness of different parts, it was necessary to have a standard scale which should look like the spectrum of the star. An exposure on the sky of about one minute gives a strong solar spectrum not unlike that of a solar-type star. The telescope with Spectrograph I attached was pointed to the north pole at about noon on a clear day, and a series of twenty-five plates with carefully timed exposures varying from 1^s to 80^s was taken. These plates, all of the same emulsion, were developed simultaneously in the same tray, so that all would receive the same photographic treatment. The 1^s exposure gave a faint image and the 80^s an over exposed one. As on any one plate the amount of the silver deposit varies in different parts of the spectrum, the region between the iron lines at $\lambda 4046$ and $\lambda 4072$ was adopted as standard.

These plates were used for the purpose of comparing the intensities on different plates of α Ceti and also on different parts of the same plate. The method of using the scale plates was as follows: The plate of the star was placed film up on the table of the measuring microscope. The different scale plates were then successively placed film down on the star plate and viewed with a low power. The scale plate whose spectrum equalled the star spectrum in density was selected, and the number of seconds which it had taken to produce the image on the scale plate, was called the intensity of the star spectrum. Of course the lines in the star spectrum interfered with the estimates, but it was usually possible to find a space where there were apparently no absorption lines. In all cases the darkest patch of spectrum in the immediate vicinity on the negative was used.

Since we do not know the exact relation between time of exposure and density of the photographic image, the estimates made with the scale plates do not give us absolute intensities. There are also many errors introduced by instrumental causes. Among other sources of error is that due to the non-achro-

FIG. 7. α CETI, 1902. VARIATIONS OF RELATIVE INTENSITY OF THE CONTINUOUS SPECTRUM.

matism of the large objective. The proportions of light of different wave-lengths which enter the slit must vary with the quality of the seeing, and the care used in guiding. The star image which falls on the slit is not homogeneous, but is composed of a central disk of $H\gamma$ light surrounded by concentric circles of light of longer and shorter wave-lengths.

The effects of different conditions of seeing and guiding were determined from plates taken of other stars, and while some differences were noticed, they were small compared with the changes observed in the case of α Ceti.

Figure 7 gives the "intensity curves" of α Ceti from three plates, which were all of the same emulsion. The intensities of the same portions of the star spectrum, were estimated on each plate by means of the scale. These estimates were plotted and, in the figure, the lines join the estimates without reference to the intensities of the other parts of the spectrum. The images on the different plates being as a whole unequal in density or blackness, the portion near $\lambda 4275$ was made equal to 10, and the estimated intensities of other portions were changed to correspond. All estimates to the red of $\lambda 4400$ refer to the brighter portions, which may be heads of bright bands.

Sidgreaves' plates showed that as the star declined in brightness, the intensity of the bright portions of the spectrum between $\lambda 4300$ and $\lambda 5000$ grew less relatively to that of the region near $\lambda 5500$. My plates show a decrease in intensity of the region from $\lambda 4300$ to $\lambda 5000$ relative to the continuous spectrum from $\lambda 4000$ to $\lambda 4300$.

Figures 3 and 5 show the changes well. Plate No. 2B is not in excellent focus and is therefore not reproduced.

It should be remembered that the solar spectrum, Figure 2, is from a negative of the sky, on a lantern-slide plate whose sensibility curve is very different from that of the Crown plates. The maximum intensity of the continuous spectrum on a Crown plate is about $\lambda 4600$ for a solar-type star.

These changes in intensity have been described as changes in the continuous spectrum, but they may be simply the fading out of some bright bands.

BRIGHT LINES.

The most noticeable and interesting features in the spectrum of α Ceti are the bright lines. The great brilliancy of some of the hydrogen lines, when the star was near its maximum, has been recorded by several observers.

The peculiar fact was noticed, that $H\alpha$, $H\beta$, and $H\epsilon$ were apparently missing, while others of the hydrogen series were very bright. Photographs, which showed $H\gamma$ and $H\delta$ as intense, gave no trace of $H\beta$ and

$H\epsilon$. Sidgreaves, in 1898 and 1899, found something which from its position might be the bright $H\beta$, but he did not consider it as certain. It has been seen bright on some plates at Harvard. [Vol. 28, Part I, H. C. O.]. Mr. Wright found $H\epsilon$ distinctly bright on a plate which he had taken in August, 1901. Figures 3 to 5 show additional evidence on this point. $H\beta$ and $H\epsilon$ were recorded as bright lines on all the dense negatives taken with Spectrograph I. They seem to have grown stronger relatively to the other hydrogen lines and also to the continuous spectrum as the star grew faint.

An attempt was made to observe $H\alpha$ visually, but without success, on the night of September 6th, 1902, when the instrument was changed to adapt it for visual work. Corresponding to the bright well-defined $H\alpha$ of the comparison spectrum there was continuous spectrum, but no bright line in the star. Mr. Wright was present and verified the observation. $H\alpha$ should be looked for when Mira is again at a maximum.

TABLE VI gives the measures of all the bright lines which appeared, sooner or later, during the course of the work. The same scheme of residuals is used as in TABLE II.

TABLE VI.—MEASURES OF BRIGHT LINES.

λ	7C	9E	13E	14F	18F	25F	27D	28D	2235D
3751.2-	....	....	....	....	....	....	—	....	....
3771.52	....	....	....	....	....	....	—	....	....
3798.76	04	....	03	....	....	....	02	....	....
3836.20	04	....	05	....	....	07	08	00	03
3853.51	....	....	01	....	....	....	00	00	....
3889.91	03	....	01	11	....	08	03	02	12
3906.36	00	....	03	....	....	04	03	09	11
3908.18	....	....	....	....	....	....	02	03	....
3933.45	....	....	....	....	....	....	09	09	....
3939.10	....	....	....	....	....	....	07	07	....
3968.49	....	....	....	....	....	....	10	10	....
3970.87	11	....	12	....	....	04	01	03	20
4007.74	01	....	01	....	....	....	....	....	....
4102.66	03	00	08	00	....	03	03	01	03
4202.91	04	....	06	....	....	00	08	06	14
4216.71	....	....	....	....	....	11	20	09	....
4234.12	....	....	03	....	....	02	13	03	10
4308.70	....	....	....	....	....	02	03	06	....
4341.33	09	04	10	13	....	15	08	00	04
4373.61	....	....	....	....	....	....	....	—	....
4376.78	....	....	....	....	....	05	07	01	....
4571.82	....	....	....	....	....	20	07	28	....
4862.34	....	....	23	....	09	14	02	03	....

Below is given a list of places which have the appearance of bright lines but which, in the judgment of the observer, are bright spaces between absorption lines. Some of the places were measured on only one plate, but the wave-lengths are probably as accurate as those of the absorption lines.

λ 3978.7
 3998.5
 4002.7
 4031.5
 4179.6
 4213.0
 4427.9
 4434.5
 4512.6
 4777.6

From the residuals of TABLE VI the probable error of the wave-length of a bright line, determined from one plate, is found to be ± 0.06 m. The wave-lengths of the bright lines show no more change than do those of the dark lines. The average residual for each plate has been computed and there is no sign of variable position. A comparison of these average residuals with those of the dark lines is as follows:

Date	Plate No.	Dark Lines.	Bright Lines.
1902 July 6	7 C	+0.02	+0.01
16	13 E	+0.06	+0.04
Aug. 4	25 F	-0.03	-0.03
11	27 D	-0.02	-0.03
25	28 D	-0.03	+0.03
1901 Aug. 17	2235 D	+0.02	-0.04

These average residuals are all so small that the agreement in sign for some cases is of little significance.

TABLE VII gives the identification of some of the bright lines. There can be no doubt that the hydrogen series is present. Metallic lines which seem to coincide in five cases are given, but in spite of the accuracy of the measures, we must consider the question of their identity to be still open.

TABLE VII.—IDENTIFICATION OF BRIGHT LINES.

α Ceti λ .	Tabular λ .	Displacement. tm.	Substance.	Authority for λ .
3751.2-	3750.15	+1.0-	H_K	Ames.
3771.52	3770.7-	+0.82	H_I	Ames.
3798.76	3798.0-	+0.76	H_G	Ames.
3836.20	3835.6-	+0.60	H_γ	Ames.
3853.51				
3889.91	3889.15	+0.76	H_ζ	Ames.
3906.36	3905.66	+0.70	Si 12	Rowland.
3908.18				
3933.45				
3939.10				
3968.49				
3970.87	3970.18	+0.69	H_ϵ	Rowland.
4007.74				
4102.66	4101.89	+0.77	H_δ	Wright.
4202.91	4202.20	+0.71	Fe 8	Rowland.
4216.71				
4234.12				
4308.70	4308.08	+0.62	Fe 6	Rowland.
4341.33	4340.63	+0.70	H_γ	Rowland.
4373.61				
4376.78	4376.11	+0.67	Fe 6	Rowland.
4571.82	4571.26	+0.56	Mg 5	Rowland.
4862.34	4861.53	+0.81	H_β	Rowland.

It should be noticed that a bright line developed on each side of each of the strong dark calcium lines, g , H and K . Without looking at the plates this might seem to be due to a double reversal of the calcium lines. Their appearance is not such, however. Mr. Wright also examined the plates with this in mind, and in his judgment the lines are separate bright lines and the phenomenon is not one of double reversal.

Several attempts were made, in June and July 1902, to secure photographs of the spectrum of Mira, with the regular three-prism instrument. It was impossible, however, to make an exposure long enough to record the continuous spectrum. The only features recorded were H_γ and two other bright lines. H_γ was single on all the plates. It seemed nearly monochromatic, but was a little sharper on the violet than on the red side. It had the same appearance as that found by Campbell in 1898 at about the same interval after the stars maximum. In 1898 he found that H_γ was triple from five to two weeks before maximum. Before observations of α Ceti were begun in 1902, it had been intended to make polariscopic tests for Zeeman effects in the bright lines; but they were found single on the first photographs and no observations for polarization were attempted. These should certainly be made when it is again possible to observe the star at maximum. Measures of the three-prism plates give the following displacements of H_γ in tenthmeters.

Date.	Plate No.	tm.
1902 July 2	2446 F	+0.65
2	2447 A	+0.68
21	2470 D	+0.65
Aug. 18	2505 E	+0.61
	Mean	+0.65 tm.

It is interesting to compare the measures of plates taken in 1902 with those of 1898. Campbell also observed the bright lines near λ 4308 and λ 4376. They were also measured on the high dispersion plate of August 18, 1902. In the following scheme under the heading "Bright Lines," is given the actual observed displacement of each bright line, corrected for the earth's motion. Under "Dark Lines" is given an assumed displacement which corresponds to that of the absorption lines in the spectrum.

Line.	CAMPBELL, 1898.		STEBBINS, 1902.		
	Three Prisms. Bright	Dark	Three Prisms. Bright Lines.	One Prism. Dark	Dark
	Lines. tm.	Lines, +62 ^{km} . tm.	tm.	Lines, +66 ^{km} . tm.	tm.
H_δ 4101.89	+0.64	+0.85	.....	+0.77	+0.90
Fe? 4308.08	+0.60	+0.89	+0.61	+0.62	+0.95
H_γ 4340.63	+0.64	+0.90	+0.65	+0.70	+0.96
Fe? 4376.11	+0.61	+0.91	+0.66	+0.67	+0.96

The dark lines in this region of the spectrum are apparently displaced about 0.25 tenthmeter farther to

the red than are the bright lines. The results obtained with one prism are systematically larger than those obtained with three prisms. This may be partly due, in the case of $H\gamma$ and $H\delta$, to overexposure on many of the plates. Since the lines seem to shade off toward the red, greater exposure probably slightly increases the apparent wave-lengths. However, since the displacement of the other hydrogen lines, which were not overexposed, are about the same as those of $H\gamma$ and $H\delta$, this effect is probably not large. The difference between the results of 1898 and 1902 is due, no doubt, to personal errors.

The bright lines at $\lambda\lambda$ 4308 and 4376, marked as possibly due to iron, are of peculiar interest. They were recorded in TABLE IV as dark lines. The appearance of each, on some of the plates, is of a bright line with an adjacent dark one on the red side. If the bright lines be due to iron, they are displaced by the same amount as the bright hydrogen lines; and if iron produces the absorption components, the displacements are equal to those of other dark lines.

A glance at the series of plates showed that there were many changes of intensity among the bright lines, both relative to each other and to the continuous spectrum. Lines not visible on the earlier plates became more intense than the hydrogen lines, which were so bright near maximum.

In order to estimate the amounts of the changes, a scale was made by the following method: An occulting strip was arranged in front of the photographic plate in the three-prism Mills Spectrograph in such a manner that only the line λ 4308.081 of the iron spectrum reached the plate. A two-second exposure gave just a trace of an image of this line, whereas ten minutes produced an over-exposed image of greater breadth and blackness than was ever obtained of the bright $H\delta$ star line. The plate-holder was moved by small successive steps along in its cell, and a series of carefully timed exposures, varying from one second to ten minutes was made. At intervals the current was switched to the other side of the comparison apparatus and an image of the same line due to an exposure of five seconds was recorded on the plate. These extra images served as a rough test of the constancy of the light, and as reference points, for the scale. The exposures were all made on the same plate and the different images received the same photographic treatment.

The bright lines of α Ceti were compared with this scale, and to each line was assigned as intensity, the number of seconds required to produce the equal line in the scale. Independent estimates of the same line made in this manner at different times are accordant with each other.

As the density of the star spectrum, as a whole,

varied greatly on the different plates, the intensities of the same line on different plates are not comparable, unless they are referred to a common standard. If the intensity of a bright line, as estimated with the scale, be divided by the intensity of the continuous spectrum on the same plate, we get what we might call the intensity of the bright line referred to the continuous spectrum. The quotients formed in this manner will be referred to as the intensities of the bright lines. It is evident that long and short exposures of the star taken on the same night should give approximately the same intensities of the bright lines. As has already been shown, there is evidence that the intensity of the continuous spectrum varied in different parts as the star faded. The intensities of bright lines were, therefore, all referred to the portion of the continuous spectrum between λ 4102 and λ 4227.

The development of the bright lines is shown in TABLE VIII. It happens that the faintest bright line to which an intensity was assigned is called 1. On plate 27D the line at λ 3908.18 was estimated with the bright line scale to be of intensity 3.5. The intensity of the continuous spectrum between $H\delta$ and g was called 24. Dividing 3.5 by 24 and multiplying by 10, an arbitrary factor, the resulting intensity of the bright line is 1. On the plate 2B the scale value of the $H\delta$ line was 250 and the continuous spectrum was of intensity 6. The resulting intensity of $H\delta$ is therefore 420. These numerical operations are crude, but they are as accurate as necessary.

In TABLE VIII a period (.) indicates that the image on the plate is dense enough and that the definition is good enough to show the line as bright, had it existed when the plate was taken, but that it was not visible. A dash (—) means that the line did not appear on the plate but that, judging from the evidence furnished by other plates, it would have been recorded with a longer exposure. Where the observer is unable to state whether the line existed or not, the space has been left blank. Plates numbered 13E, 18F, 21F, and 25F, and those of Mr. Wright, are Isochromatic and are therefore not strictly comparable with the Crown plates.

The short exposures 3C and 4E give results fairly consistent with the long exposure 2B, taken on the same night. The plates 8D and 9E do not agree at all with the denser negative of 7C. This discordance shows that the estimates are very rough.

Another source of error is the effect of widening the slit for the long exposures. This might easily produce a progressive change in the apparent intensity of the lines relative to the continuous spectrum, but it certainly could not produce such great variation among the lines themselves.

TABLE VIII.—INTENSITIES OF BRIGHT LINES.

Date Plate Number Mag. of Star Intensity of Continuous Spectrum	CROWN PLATES						ISOCHROMATIC PLATES						CROWN PLATES						ISOCHROMATIC			
	1902																		1901			
	June 27 2B	3 C 3.8	4 E	July 6 7 C	8D 4.1	9E	July 16 13E 4.6	July 22 18F 5.1	July 29 21F 5.3	Aug. 4 25F 5.4	Aug. 11 27D 5.6	Aug. 25 28D 6.4	Sept. 6 33D 7.0	Sept. 22 39D 7.0	Oct. 4 42A 7.8	Oct. 26 48A 8.5	Aug. 3 2211C —	Aug. 17 2235D —				
	6	2.0	1.5	9.5	1.4	2.0	7.5	7	7	11	24	17	6.5	7	5	2.0	2.9	9				
Hκ 3751.2—	—	—	—	—	—	—	—	—	—	—	faint	—	—	—				—				
Hι 3771.52	—	—	—	—	—	—	—	—	—	—	2	—	—	—				—				
Hθ 3798.76	—	—	—	3	—	—	3	—	—	—	2	—	—	—				—				
Hη 3836.20	9	10	—	12	—	—	13	8	4	2	6	4	4	—				6				
3853.51	.	.	.	.	.	.	3	—	—	—	4	4	—	3				.				
Hζ 3889.91	33	40	20	34	27	—	41	26	21	14	17	11	13	7	5	14	16					
3906.36	4	—	—	7	—	—	6	4	—	2	5	5	6	5				4				
3908.18											3	3	—	—								
3933.45											1	2	—	3								
3939.10											4	5	7	8								
3968.49											4	5	8	5								
Hε 3970.87	4	—	—	9	—	—	12	13	13	11	17	14	17	10				4				
4007.74	6	—	—	9	—	—	—	4	.	.	.	.	.	.				.				
Hδ 4102.66	420	600	410	220	140	50	290	390	390	260	120	100	90	40	30	13	140	190				
4202.91	10	—	—	9	—	—	13	14	19	21	12	21	32	31	30	40	21	17				
4216.71	.	.	.	.	.	.	.	.	.	6	4	6	14	14	13			.				
4234.12	.	.	.	.	.	.	8	—	7	7	4	6	11	6	12			7				
4308.70	.	.	.	.	.	.	.	.	12	13	9	13	35	37	48	60		.				
Hγ 4341.33	420	520	280	130	90	34	160	240	190	170	80	70	70	30	24	13	80	60				
4373.61	.	.	.	.	.	.	.	.	.	3	2	5	9	8	6			.				
4376.78	.	.	.	.	.	.	.	11	8	8	6	8	15	15	12			.				
4571.82	.	.	.	.	.	.	.	.	.	12	7	15	28	60	90	75		.				
Hβ 4862.34	17	—	—	10	—	—	8	5	5	6	8	9	11	12	11			3				

The changes of the lines are shown graphically in Figures 8 to 13. The intensities are represented by ordinates. It will be seen how the hydrogen lines, $H\gamma$ and $H\delta$, decreased in intensity as the star grew faint. In Figure 8, Plate 2B, the intensity of $H\gamma$ has been arbitrarily reduced to accord with the evidence furnished by the other plates taken on the same night. Figures 8 to 12 truthfully indicate the development of the bright lines from $H\delta$ to the red. In Figure 13 and to the violet of $H\delta$ on the other plates, the data are insufficient on account of under-exposure. The line at $\lambda 4007$ was the only one which certainly disappeared during the interval covered by these six plates. The development of the line at $\lambda 4571$ was remarkable. This line, which is perhaps due to magnesium, did not appear until the star was of about magnitude 5.4, and as the star grew fainter it became the most prominent object in the spectrum.

The images on the plates following 48A are not strong enough to give results which can be entered in TABLE VIII. A brief summary of what was found on the plates may be of interest.

54A. Bright lines 4202, 4308 apparently present, 4571 certain. No trace of any continuous spectrum.

58A. Bright lines 4202, 4308, 4571 all certain. Faint continuous spectrum from $\lambda 4000$ to $\lambda 4800$.

59A. Bright line 4202 not found. 4308, 4571 present. Faint continuous spectrum from $\lambda 4000$ to $\lambda 4150$, also from $\lambda 4200$ to $\lambda 4585$.

On 58A and 59A the continuous spectrum was visible in the $H\gamma$ and $H\delta$ regions, but no trace of a bright line was seen in either case. The evidence furnished by these later plates therefore strengthens the conclusion that the bright hydrogen lines disappeared at minimum. $H\gamma$ and $H\delta$ would certainly have been recorded if they had remained as intense as they were a month preceding minimum. Figures 8 to 13 show that $H\gamma$ and $H\delta$ were growing fainter as the star declined, and the lines $\lambda 4202$, $\lambda 4308$, and $\lambda 4571$ were increasing in intensity as far as Plate 48A. I am not prepared to say whether the intensities of these last three lines increased or decreased after that time, but they did not change much. It is certain that no new bright lines appeared which were as prominent as those already under observation, for the plates were carefully examined. In fact the lines on Plate 54A were entirely overlooked on the first examination.

While the method of estimating intensities here presented is subject to many errors, it affords a better idea of the changes than could be given by a mere description. All the estimates with the bright-line and continuous-spectrum scales were made in such a way as to avoid personal bias. The observer did not know, when using the scales, how the final intensities would come out, and the relative changes observed in the continuous spectrum and in the bright lines are real.

Until this star has been successfully followed

o CETI, 1902. INTENSITIES OF BRIGHT LINES.

through all its phases, it is obviously too soon to advance any theory to account for the observed changes in its spectrum or in its brightness. The light gathering power of the great refractor is not sufficient to follow the spectrum satisfactorily, at least not on the dispersive scale used by me. An ideal equipment for work on variables would consist of a large reflector which could be used for this purpose alone, with spectrographs of various dispersive powers arranged for use in all parts of the spectrum.

The apparent constancy of radial velocity is strong evidence that the variations in brightness are not due to the influence of a companion star, unless, indeed, the companion were of very small relative mass, were moving in a very eccentric orbit and approached very close to the primary. The displaced system of bright lines could not belong to such a companion, as their wave lengths are apparently constant. The large irregularities in the period of the light curve practically preclude the question of a binary system, though perhaps not absolutely so.

The remarkable distribution of light in the hydrogen series seems as yet impossible to explain. Miss Clarke has explained the apparent absence of H_{ϵ} by assuming the hydrogen to be at a lower level in the star's envelope than the calcium layer, the H calcium absorption destroying the H_{ϵ} radiations. This theory may still be true, though the existence of a faint bright H_{ϵ} has been proven. However, H_{β} and H_{α} are much more reduced in intensity than is H_{ϵ} ; and with them there is no evidence of overlying absorption strata. It is usually expected that the bright hydrogen series will diminish in intensity from red toward the violet.

This appears to hold even for new stars, in which the disturbance has been very sudden, though exception should perhaps be made for H_{α} when new star spectra approach the nebular form. The supposition that in Mira the hydrogen series may regularly decrease in brightness from violet to red is not tenable, as the diminution from H_{γ} to H_{β} is entirely too great. Inasmuch as the bright lines are strongly shifted (to the violet with reference to the dark-line system) from their normal positions apparently by causes other than radial velocity and pressure, it seems probable that the peculiarities of the hydrogen-line intensities are due also to causes now unknown to us. The presence of the bright iron lines $\lambda 4308$ and $\lambda 4376$, the absence of others of the same element, and the diversity of structure observed by Campbell in the triple H_{γ} and H_{δ} bands are perhaps due to similar unknown causes.

The great variations of relative intensity observed in the hydrogen and other bright lines, and in the continuous spectrum, show that the star's decrease in light is produced by other causes than general absorption.

Considering all the evidence, it seems reasonably certain that the star's variation in brightness is due to the action of internal forces.

I beg to acknowledge my indebtedness to Director Campbell who provided the necessary apparatus and made valuable suggestions during the course of the work; to Messrs. Wright and Reese, for continual advice and assistance, and to Dr. H. D. Curtis, for enlarging the negatives for reproduction.

JOEL STEBBINS.

May 1, 1903.

OBSERVATIONS OF THE BRIGHTNESS OF OMICRON CETI IN 1902-1903

The brightness of $\omicron$ Ceti was observed by Argelander's method about once a week, beginning with June 23, 1902. At first the star's magnitude was determined with the naked eye or opera glass. After it had become too faint to be seen with an opera-glass, the three-inch finder of the twelve-inch telescope was used.

In order to avoid prejudice the observations in "grades" were made, recorded and then laid aside, to be reduced a month or two later. When observing, I did not know the magnitude of any of the comparison stars, and in but few cases did I remember what the estimate on any previous night had been.

The magnitude of all stars brighter than 7.00 were taken from the Harvard Photometry, Vol. 45, Annals H.C.O. For the fainter stars the adopted magnitudes are those of H. M. Parkhurst, given in Vol. 29, page 144 of the same publications. No stars that are not in one of these two sources, were used for the comparisons.

The value of one "grade" has been determined from the observations to be 0.11 magnitude. However, most of the comparisons were made and reduced in such a manner that the resulting magnitude is independent of the value of a grade. For the sake of uniformity all estimates were made in grades and it was tried to keep the value of one grade as nearly constant as possible. In reducing observations where $\omicron$ Ceti was compared with two stars, one brighter and one fainter, the magnitude of the variable has been taken proportionally between them. In taking the mean of several estimates, an estimate derived from two stars has been given twice the weight of an estimate based upon a single comparison star. As a hundredth of a magnitude is of little significance in observations of this kind, the final means have been rounded off to the nearest tenth of a magnitude, but the light curve, shown in Figure 1, was drawn with the means taken to hundredths. Evidence of the Purkinge phenomenon shows in the change from opera-glass to the three-inch

finder. After January 10, 1903, the observer was in residence at Berkeley, and a few observations of brightness were made there with various instruments.

REFERENCE LETTERS AND MAGNITUDES ADOPTED FOR THE COMPARISON STARS.

Let.	Mag.	DM.	Name.	R.A. 1900.	Decl. 1900.
<i>a</i>	3.64	-10°240	η Ceti	1 ^h 03 ^m 6	-10° 43'
<i>b</i>	3.64	+ 2°422	γ Ceti	2 38.1	+ 2 49
<i>c</i>	3.71	-16°295	τ Ceti	1 39.4	-16 28
<i>d</i>	3.86	- 8°244	θ Ceti	1 19.0	- 8 42
<i>e</i>	3.90	- 0°406	δ Ceti	2 34.4	- 0 06
<i>f</i>	3.91	+ 2°317	α Piscium	1 56.9	+ 2 17
<i>g</i>	3.96	-11°359	ζ Ceti	1 46.5	-10 50
<i>h</i>	4.30	+ 7°388	ξ^2 Ceti	2 22.8	+ 8 01
<i>i</i>	4.33	+ 9°359	μ Ceti	2 39.5	+ 9 42
<i>j</i>	4.46	+ 8°273	$\circ$ Piscium	1 40.1	+ 8 39
<i>k</i>	4.62	+ 4°293	ν Piscium	1 36.2	+ 4 59
<i>l</i>	4.73	+ 8°455	λ Ceti	2 54.4	+ 8 31
<i>m</i>	4.88	+ 2°290	ξ Piscium	1 48.4	+ 2 42
<i>n</i>	5.05	+ 4°418	ν Ceti	2 30.6	+ 5 09
<i>p</i>	5.22	- 4°260		1 37.7	- 4 11
<i>q</i>	5.54	- 1°353	75 Ceti	2 27.1	- 1 28
<i>r</i>	5.63	- 3°336	66 Ceti	2 07.7	- 2 52
<i>s</i>	5.64	- 1°322	70 Ceti	2 17.1	- 1 20
<i>t</i>	5.66	- 7°393	67 Ceti	2 12.0	- 6 53
<i>u</i>	5.73	- 1°377	84 Ceti	2 36.1	- 1 08
<i>w</i>	5.76	+ 1°410		2 12.8	+ 1 17
<i>x</i>	6.00	- 2°375	63 Ceti	2 06.5	- 2 18
<i>y</i>	6.30	- 3°374	71 Ceti	2 20.0	- 3 14
<i>z</i>	6.47	- 5°438		2 14.6	- 4 48
<i>A</i>	6.71	+ 0°370		2 10.1	+ 0 15
<i>B</i>	6.8-*	- 4°394		2 20.0	- 4 20
<i>C</i>	7.27	- 3°372			
<i>D</i>	7.33	- 3°340			
<i>E</i>	7.86	- 2°389			
<i>F</i>	8.12	- 4°379			
<i>G</i>	8.44	- 3°375			
<i>H</i>	8.65	- 4°390			
<i>I</i>	8.80	- 3°371			
<i>J</i>	8.95	- 3°363			
<i>K</i>	9.35	- 3°347			
<i>L</i>	9.44	- 3°355			
<i>M</i>	9.48	- 3°373			
<i>N</i>	9.99	- 3°362			

* Harvard magnitude 7.06, has 8.5 magnitude companion. Combination of the two assumed 6.8 magnitude.

OBSERVATIONS OF THE BRIGHTNESS OF α CETI.

Astronomical Date. 1902	Greenwich Mean Time.	Comparisons.	Mag.	Mean.
June 23	23 ^h 5	$v = b$	3.64	
		$v 2 g$	3.74	
		$a 2 v$	3.86	
		$v 2 f$	3.69	
		$v = d$	3.86	3.8
27	22.8	$b 2 v$	3.86	
		$f 1 v$	4.02	
		$v 2 g$	3.74	
		$v 2 c$	3.49	
		$v 4 e$	3.46	
		$d 2 v$	4.08	3.8
July 2	22.9	$b 2 v 2 e$	3.77	
		$v = f$	3.91	
		$g 2 v 2 i$	4.14	
		$d 2 v 3 m$	4.27	4.0
6	22.8	$v = e$	3.90	
		$f 1 v 3 m$	4.15	
		$d 2 v 2 h$	4.08	
		$g 2 v 3 i$	4.11	4.1
14	22.2	$e 3 v 2 m$	4.49	
		$i 1 v 1 l$	4.53	
		$v = k$	4.62	
		$v = j$	4.46	4.5
18	23.1	$v = k$	4.62	
		$v = m$	4.88	
		$j 2 v 3 n$	4.70	4.7
22	23.1	$v = n$	5.05	5.0
29	22.6	$v = p$	5.22	
		$n 2 v 2 t$	5.36	
		$m 5 v 5 s$	5.26	5.3
August 4	23.1	$v = t$	5.66	
		$n 2 v 2 s$	5.34	
		$p 3 v 2 q$	5.41	5.4
11	22.7	$v = s$	5.64	
		$v = n$	5.73	
		$q 2 v 2 r$	5.58	5.6
18	23.8	$r 2 v 2 x$	5.81	
		$v = w$	5.76	
		$s 3 v 3 y$	5.97	5.9
25	22.2	$v = y$	6.30	
		$v = z$	6.47	
		$x 2 v 3 B$	6.42	6.4
September 3	20.8	$B 2 v 2 D$	7.06	
		$v = A$	6.71	6.9
6	21.6	$B 2 v 2 D$	7.06	
		$y 6 v 4 C$	6.88	7.0
9	22.5	$v 2 C$	7.05	7.0
17	19.5	$v = B$	6.80	
		$y 8 v 3 C$	6.98	
		$v 3 D$	7.00	6.9

OBSERVATIONS OF THE BRIGHTNESS OF α CETI.—(Continued.)

Astronomical Date. 1902	Greenwich Mean Time.	Comparisons.	Mag.	Mean.
September 27	19 ^h 8	$v = C$	7.27	
		$v = D$	7.33	7.3
October 5	18.5	$v = C$	7.27	
		$E 4 v 2 F$	8.04	7.8
8	19.0	$E 5 v 2 F$	8.05	
		$C 2 v 3 G$	7.74	7.9
15	19.3	$v 2 G$	8.22	
		$E 5 v 2 F$	8.05	8.1
27	19.0	$F 3 v 2 J$	8.61	
		$v 1 H$	8.54	
		$v 2 I$	8.58	8.6
November 11	19.8	$v = J$	8.95	
		$v = I$	8.80	
		$H 2 v 4 M$	8.93	8.9
17	17.8	$I 2 v 3 M$	9.07	
		$J 3 v 6 L$	9.11	9.1
24	19.8	$J 5 v 5 N$	9.47	
		$v 4 L$	9.00	
		$v 2 K$	9.13	
		$I 2 v 2 M$	9.14	9.2
December 12	19.5	$J 2 v 5 L$	9.09	
		$v = I$	8.80	9.0
24	17.8	$J 2 v 2 K$	9.15	
		$v 5 L$	8.89	9.1
1903				
January 3	16.8	$J 3 v 3 K$	9.15	
		$v = I$	8.80	9.0
29	16.2	$v = J$	8.95	
		$G 2 v 2 H$	8.54	8.7
February 28	16.0	$V 2 C$	7.05	7.0
March 17	15.5	$m 5 v 5 q$	5.21	5.2

REMARKS.

- June 27. Fifth comparison assigned $\frac{1}{2}$ weight on account of interval of 4 grades.
- August 18. First of opera glass series.
- September 3. Could see v with naked eye.
- September 17. First with three-inch finder.
- October 5. Identifications certain.
- October 8 and 15. Remembered comparison with E and F on October 5.
- January 29. Berkeley. One-inch telescope.
- February 28. " Two-inch telescope.
- March 17. " Opera glass.

JOEL STEBBINS.

May 1, 1903.