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THE SPECTRUM OF COMET BROOKS (1911c)

The spectrum of Brooks's comet (1911c) was observed here during September and October, 1911, using slit spectrographs and a prismatic camera. The instruments were briefly as follows:

A. A single-prism spectrograph attached to the 92 cm. (36-inch) refractor, and described as Spectrograph I in previous publications.¹

B. The same spectrograph, fitted with a $63\frac{1}{2}^\circ$ flint-glass prism and a camera lens corrected for the D region of the spectrum. This arrangement gives good definition over the visual region as far as 7065Å.

C. A one-prism spectrograph, attached to the 31 cm. (12-inch) refractor, which gives good definition over the whole observable spectrum.

D. A quartz spectrograph containing two 60° Cornu quartz prisms, and quartz lenses of 5 cm. (2 inches) aperture and 28 cm. (11 inches) focal length.

E. A prismatic camera composed of two 60° flint-glass prisms in front of a camera lens of 4.1 cm. ($1\frac{5}{8}$ inches) aperture and 12.7 cm. (5 inches) focal length, the focal ratio being 1:3.1. This instrument introduces a pronounced distortion of the image, resulting in an apparent curvature of the images of the comet's tail analogous to the curvature of the lines in a prism spectroscope.

A journal of observations is given in Tables I and II.

The photographs with the prismatic camera were usually secured by attaching the apparatus to telescopes of other observers who were photographing the comet, and who kindly consented to make the exposures. The names of these gentlemen appear in the third column of Table II.

TABLE I

OBSERVATIONS MADE WITH SLIT SPECTROGRAPHS

Plate number	G. M. T. 1911	Length of exposure	Instrument	Slit width* ² (in Angströms)
325	Oct. 3.68	36'	D	10.5 $(\lambda-1784)^2 \times 10^{-7}$
327	5.70	95	C	5.6 $(\lambda-2150)^2 \times 10^{-7}$
331	18.04	50	D	15.0 $(\lambda-1784)^2 \times 10^{-7}$
333	22.05	78	B	5.6 $(\lambda-2417)^2 \times 10^{-7}$
335	23.05	75	B	5.6 $(\lambda-2417)^2 \times 10^{-7}$
337	29.05	65	A	6.6 $(\lambda-2160)^2 \times 10^{-7}$
338	Oct. 29.05	88	C	8.1 $(\lambda-2150)^2 \times 10^{-7}$
340	Nov. 1.05	75	B	16.8 $(\lambda-2417)^2 \times 10^{-7}$
341	Nov. 1.04	75	C	24.3 $(\lambda-2150)^2 \times 10^{-7}$

TABLE II

OBSERVATIONS WITH THE PRISMATIC CAMERA

G. M. T. 1911	Length of exposure	Exposed by	Remarks
Sept. 13.67	2h 0m	Kiess and Sheppard	
14.71	2 45	Sheppard	
18.69	1 30	Sheppard	
Sept. 27.69	2 4	Sheppard	
Oct. 2.68	2 5	Sheppard	Plate fogged by moonlight
10.64	0 30	Curtis	
12.63	0 31	Curtis	
22.03	0 40	Curtis	
23.03	0 54	Curtis	
Oct. 29.03	0 47	Wilson	
Nov. 1.03	0 43	Sheppard	

The plates taken with the objective prism show the main features of the spectrum of the head and nucleus, and in addition a series of nine double or multiple images of the tail corresponding to those radiations which have been called by Professor Fowler the "tail bands." These photographs cover the region between 3750Å and 5200Å. One attempt was made to photograph the less refrangible end of the visible spectrum with this apparatus, but the record

*²The expressions in this column give the equivalent in angströms of the width of the geometrical image of the slit on the photographic plate.

¹ *L. O. Bulletins*, 1, 46, 1901; 3, 22, 1904.

is very faint. The wave lengths of the stronger of these lines were determined by the slit spectrograph and are given in Table IV. An inspection of the plates shows that the remaining images correspond closely in position with those observed in Morehouse's comet (1908c), the wave lengths of which, as determined by Pluvinel and Baldet³ are: 378–380, 411–414, 438–441, 485–488, 502–511 μ .

An interesting fact brought out by the objective-prism spectrograms is that the tail bands, which were quite faint at first, increased in intensity as the comet approached perihelion, finally becoming conspicuous features of the spectrum as observed with an objective prism. A few of the photographs, reproduced in Plate I, illustrate this development very well. On the photograph of September 13 they are visible, but faint, while the ordinary features of the comet's spectrum are strongly recorded. On September 27 their brightness had increased considerably, and by the end of October the tail images may be said to have been the most conspicuous features exhibited by the photographs. The comet passed perihelion on October 28. It would be a matter of interest to know whether a corresponding decrease in intensity occurred as the comet receded from the Sun. Our last observation was on November 1; after which observing conditions here were poor, while the comet's rapid southward motion soon carried it out of reach of the instruments. It is to be hoped that observers in the southern hemisphere were able to secure later observations with suitable apparatus.

The spectrum of the comet, in its general features, very much resembles those of Halley's comet, Daniel's comet (1907d), and the great "daylight comet," 1910a. The resemblance to the latter is the more marked by reason of the comparative strength, in both spectra, of the band at 4195–4202A. This band seems to be a composite one, and is unquestionably much stronger in Brooks's comet and 1910a than in Daniel's comet.

Both the slit spectrograms and the photographs taken with the prismatic camera show that marked changes occurred in the relative intensities of some of the bright lines in the head and nucleus. On the objective-prism plate of September 13 the group of lines at 4193–4216A is much fainter than that at 4040–4052A, while on October 22 the former group is very much the stronger. The same variation is exhibited by the slit spectrograms of October 5, 28, and 30. The entire group of bands between 4000A and 4075A seems to have become relatively faint as the comet approached the Sun, while the cyanogen band at 4215A and the band at 4195A became much stronger.

It appears to be quite characteristic of the con-

tinuous spectrum of the nucleus of a comet that it practically ends in the vicinity of the cyanogen band at 3883A, and is relatively rich in light of the less refrangible end of the spectrum. This was the case with 1910a, and was found to be so in Halley's comet, in a series of observations an account of which has not yet been published.⁴

That a considerable part of this continuous spectrum is reflected or diffused sunlight is shown by the occurrence of the Fraunhofer lines in the spectrum of the nucleus. While these lines are more pronounced in the blue-violet than in the less refrangible regions of the comet's spectrum, as is indeed the case in that of the Sun, the stronger lines, such as $H\beta$, 4958A, the b group, a and $H\alpha$, occur throughout the spectrum of the comet, and it may therefore fairly be assumed that a considerable part of the comet's continuous spectrum is diffused or reflected sunlight. The facts here referred to are significant as having a bearing upon the question of the size of the cometary particles,—if they are particles in the ordinary sense of the word—which scatter the sunlight in the nucleus of a comet. In the absence of an accurate knowledge of the intensity curve of the comet's continuous spectrum only the most general conclusions can be drawn. Inasmuch, however, as the light of the sky extends with only gradually diminishing intensity far to the violet of 3880A it is certain that the elements in the nucleus which diffuse, scatter or reflect the sunlight must be larger than the particles which perform a similar function in the atmosphere of the Earth. An estimate of the intensity curve of diffused sunlight, as accurate as the circumstances of observation permit, would doubtless be of value in fixing the minimum average size of the elementary components of the comet's nucleus.

Most of the bright lines and bands in the spectrum can be classified as nucleus, head and tail bands, according to the locality of their occurrence. Taking these up in reverse order, the tail bands may be said to be visible throughout the comet, being somewhat stronger in the head than in the remote parts of the tail. The carbon and cyanogen bands occur to a greater or less extent throughout the head, and the brighter ones are visible for a distance in the tail.

⁴ This was first suspected from observations made with spectroscopes attached to refracting telescopes; but since such combinations are not suitable for the determination of relative intensities in different parts of the spectrum Brooks's comet was photographed with the quartz spectrograph attached to the Crossley reflector (Observations no. 325–331, Table I). These photographs, particularly the second, compared with one of the sky made with the same instrument, leave no doubt as to the absence of ultraviolet light in the continuous spectrum of the nucleus. The spectrum can be traced only a short distance above the cyanogen band, while that of the sky continues with but gradually diminishing intensity until it is finally lost through the transparency of the silver surface of the mirror (3200A $\pm$).

³ *Astrophysical Journal*, 34, 89, 1911.

These, with the line at 4364A, the D lines and probably the line 6300A, may be said, I think, to include all of the head bands, though this is a matter somewhat difficult to decide, particularly in dealing with spectrograms secured with the large telescope. The comet, when under observation, was always close to the horizon, and the irregularities in following occasioned by the rapid changes in refraction, combined with those resulting from the rather inaccessible position of the eye-end of the telescope, made it difficult to keep the nucleus central on the slit. The remaining lines all appear to have their origins pretty close to the nucleus. The line at 4313A seems to be particularly short and concentrated.

Measures have been made of the widths of some of the bands recorded by the prismatic camera for the purpose of estimating the extent of the occurrence of the brighter carbon and cyanogen lines. These measures are only roughly approximate, as the camera with which the photographs were made has a focal length of but 12.7 cm. (5 inches). However, in view of the nebulous character of some of the features measured, it is perhaps doubtful whether a larger image would have offered decided advantages. The knots corresponding to some of the bright lines are very indefinite, and their diameters are, in fact, functions of the length of exposure; but the measures will give a rough idea of the extent of the volumes through which the various radiations manifest themselves. The results are given in Table III, which requires a word of explanation. Each of the carbon and cyanogen bands may be said to have a dense core, from which, on some of the plates, the spectrum fades away on either side to vanishing intensity. The term "edge of nebulosity" refers to settings as far out as any darkening of the plate could be detected. Such measurements are of course very uncertain, and will vary greatly with the exposure of the plate and the judgment of the observer. Where no measurements are entered under this head, outlying nebulosity was not observed. The measures on the edges of the core represent something more definite, but even here the same considerations enter, but in a lesser degree. Allowance must be made for a large aberrational constant, on account of the small scale of the photographs. For instance, slit spectrograms show the line 4313A to be practically confined to the nucleus, which had usually a diameter of only a few seconds, while the diameter of this image, as measured on the photographs, is 0.045 mm., corresponding to 1.3 minutes of arc. This probably represents the diameter of a stellar image, under the conditions of observation, and half of this amount might appropriately be subtracted from the other distances given in the table. The measurements

are from the center of the continuous spectrum, those on the left side of the table being toward the Sun, those on the right in the direction of the tail.

TABLE III
SEPTEMBER 13.7
G. M. T. 1911

λ	Edge of nebulosity	Edge of core	Edge of core	Edge of nebulosity
388	9'5 22.0×10^4 km.	1'7 3.9×10^4 km.	1'2 2.7×10^4 km.	21'7 53.0×10^4 km.
405 ^s		0.5 1.1×10^4 km.	0.7 1.5×10^4 km.	
470	8.0 18.0×10^4 km.	1.6 3.8×10^4 km.	1.5 3.4×10^4 km.	11.0 25.0×10^4 km.
SEPTEMBER 14.7				
388	14'0 32.0×10^4 km.	1'4 3.2×10^4 km.	0'9 2.0×10^4 km.	15'0 38.0×10^4 km.
422		1.1 2.5×10^4 km.	0.9 2.0×10^4 km.	
431 ^s		0.8 1.8×10^4 km.	0.5 1.1×10^4 km.	
470	8.0 18.0×10^4 km.	0.9 2.0×10^4 km.	1.4 3.2×10^4 km.	11.0 25.0×10^4 km.
OCTOBER 23 ^s				
388		1'4 4.7×10^4 km.	2'3 7.7×10^4 km.	11'0 37.0×10^4 km.
422		0.8 2.7×10^4 km.	2.3 7.7×10^4 km.	
470		1.2 4.0×10^4 km.	0.8 2.7×10^4 km.	4.0 13.4×10^4 km.
OCTOBER 29				
388	5'4 20.0×10^4 km.	0'8 3.0×10^4 km.	1'5 5.7×10^4 km.	12'0 45.0×10^4 km.
422		0.9 3.4×10^4 km.	0.7 2.6×10^4 km.	*7
470		1.1 4.2×10^4 km.	1.1 4.2×10^4 km.	*7
NOVEMBER 1				
388		1'8 7.3×10^4 km.	1'3 5.3×10^4 km.	8'0 32.0×10^4 km.
422		1.1 4.4×10^4 km.	0.7 2.8×10^4 km.	
470		1.1 4.4×10^4 km.	2.3 9.3×10^4 km.	

From these measures it is seen that the blue carbon band is emitted with a fair degree of strength throughout a volume varying from 50,000 to over 100,000 km. in diameter, and with less intensity through one measuring somewhat less than half a million kilometers. The outlying nebulosity is more pronounced in the earlier plates. Cyanogen, as indicated by the third band, is more extensively distrib-

^s A nucleus line, almost stellar on plate.

⁶ On this plate the tail, as recorded by the tail bands, extends clear across the field, the included portion being about 10° long, corresponding to a length of tail of over 20,000,000 km.

*7 The tail bands at 470μ interfered with the measurement of the fainter part of this band on this side.

uted, and the extension in the direction of the tail is more pronounced.

Plates 338 and 341 record, among other features of the comet's spectrum, the tail bands, and therefore furnish a somewhat more accurate determination of their wave lengths than can be obtained with the prismatic camera. The only previous determinations of the positions of these lines by means of slit spectrographs are those by Campbell and Albrecht⁸ and by H. D. Curtis,⁹ from measures of the spectrum of Morehouse's comet (1908c). As the conditions under which these observers worked do not seem to have been of the best, the present independent determination of the wave lengths is perhaps not without value. Both of the plates mentioned at the beginning of this paragraph were made with a comparatively long slit, the equivalent in minutes of arc being 3.5. The equivalents in angströms of the slit widths used are as follows:

λ	Oct. 29 Plate no. 338	Nov. 1 Plate no. 341
4000	2.8A	8.3A
4500	4.5A	13.4A
5000	6.6A	19.7A

In the earlier plate the nucleus is central on the slit, while in the other it lies at the extreme end, the slit extending along the declination circle in the direction of decreasing right ascension, that is, in the general direction of the tail. The second plate was taken only for the purpose of getting the tail bands. The following are the wave lengths of these bands, as measured on the two plates:

TABLE IV

Low pressure carbon monoxide (Fowler)	Oct. 29 No. 338		Nov. 1 No. 341 (wide slit)	
	λ	i	λ	i
4001.3	4001	0	4003	1
4020.4	4021	0	4023	1
	4230.0	0		
	4238.9	0	4238	00
4253.2	4254.0	1—	4256	1
4276.0	4277.0	1—	4278	1
	4526	00	4524	00
4545.4	4547.0	0	4547.4	1
4570.5	4573	0	4571.2	1
			4691	0*
4688.5			4719	0*
4715.0				

* Difficult to measure on account of faintness and proximity to strong lines of the blue carbon band.

The wave lengths given in the first column are the laboratory determinations by Fowler. Professor Fowler has observed the bands to be shaded on the less

refrangible side, which probably accounts for the fact that the measures of the comet lines come out a little larger than his values. On the plate of October 29 these lines are readily seen to be hazier than most of the other bright lines, but for the other plate the slit was so wide that all lines appear equally broad. The line at 4230A was observed on only one plate, but there appears to be no question as to the reality of its existence. It may be remarked that it forms, with the rest of the group, a series, the second differences of which are constant within the limits of possible error. The lines at 4238A and 4525A do not appear to have been observed by Fowler, but were undoubtedly found in Morehouse's comet by Pluvinel and Baldet.

The wave lengths of lines measured on a number of the slit spectrograms are given in Table V. Many of these lines have been observed by other observers, notably Dr. Campbell, in the spectra of earlier comets. There are some, however, which, so far as I am aware, have not heretofore been found. Among these may be mentioned the one near 4202A, which probably varies greatly in intensity in different comets, and the line at 4607.6A, which may be the head of the first cyanogen band, observed by Kayser, at 4606A.¹⁰ In the lower end of the spectrum a good many of the lines appear to be new. In considering the intensities of the lines, as given in the table, the effect of chromatic aberration of the refracting telescopes must of course be borne in mind.

In measuring the spectrum of a comet which consists, in general, of bright lines superimposed on a solar spectrum one must exercise all possible care to distinguish between bright radiations, and bright patches of continuous spectrum between neighboring dark lines. In measuring these plates I have compared them with spectra of the sky photographed with the same instruments, and in cases of doubt the "bright lines" have not been recorded. For instance, there are two faint brightenings on either side of the strong dark line at 4958A. On referring to the solar spectrum we see that on either side of the corresponding dark Fraunhofer line there are areas comparatively free from dark lines, which gives an effect, in a low dispersion solar spectrogram, somewhat similar to that observed in the comet. Similar considerations apply to the part of the spectrum in the vicinity of the *b* group. It is believed that, in view of the precautions taken, the bright radiations given in the table are all fairly certain.

The series of maxima and minima between 6560A and 6630A present the appearance of a faint band, though the dispersion is so low in this region as to leave the matter in some doubt. The probabilities are

⁸ *L. O. Bulletins*, no. 145, 5, 58, 1908.

⁹ *L. O. Bulletins*, no. 163, 5, 135, 1909.

¹⁰ *Astronomy and Astrophysics*, 13, 205, 1894.

that it is such a band. The measured position of the dark C line is about $1\frac{1}{2}\text{\AA}$ too small, and it has probably been crowded toward the violet by the bright band in question.

The first carbon band, 5954–6188A, was not recorded on any of the plates. There have been reports of its existence in the spectrum of this comet, but it seems possible that one of the other bands in this region was mistaken for it. It will be recalled that Campbell observed visually in the spectrum of comet 1893b a faint band at $601\mu\mu$ which was thought to be identical with the carbon band.¹¹ It is not unlikely, however, that it consisted of the three lines 5977, 5994, and 6021 occurring in the spectrum of Brooks's comet.

Kayser has shown that the apparent position of maximum intensity in such bands as those which compose the band spectrum of carbon is affected by the slit width used in making the observation, and in this way he explained the fact that the wave lengths of the corresponding cometary bands have always been observed too small.¹² His numerical computations for the band at 4737A, based on certain estimates of the distribution of intensity within the band, call for a displacement of the maximum in the direction toward the violet end of the spectrum of about 0.4 of the width of the image of the slit, assuming the slit to be comparatively narrow. In this connection it should be said that in measuring these comet spectra the attempt was made to place the micrometer wire on the maximum of the band. This is the procedure advised by Kayser. It is sometimes the practice of observers to set the wire on the extreme edge of the band and to subtract one-half of the width of a neighboring comparison line of suitable intensity, in order to determine the position of the edge. In comparing the measurements of comet spectra the fact that there are two methods of measurement in vogue should be recognized. The following data, based on wave lengths given in Table V and on Kayser and Runge's wave lengths of the carbon bands, would seem to indicate a somewhat smaller displacement (for comparatively narrow slits) than that called for by Kayser's theory.

Plate number	333	335	337	338 ¹³
Slit width	3.0A	3.0A	4.3A	5.4A
λ	DISPLACEMENTS			
4737.18	— .6A	— .9A	—1.0A	—1.4
4715.31	— .5	— .8	— .9	—2.
4697.57	— .8	— .5	—1.1	—2.
4684.94	— .3	—1.1	— .6	
(4678.8)	(—1.0)	(— .8)	(— .7)	

¹¹ *Astronomy and Astrophysics*, 12, 652, 1893; 13, 205, 571, 1894.

¹² *Astronomy and Astrophysics*, 13, 367, 1894.

¹³ The band is somewhat out of focus on this plate.

Unfortunately Kayser and Runge do not appear to have measured the position of the fifth head of this band. The value given in brackets is Hasselberg's determination plus a correction of 1.2A, which represents the mean of the differences between Kayser and Runge's wave lengths of the first four bands and his. The value can not be considered as reliable as the other four, but the residuals obtained for it are inserted for completeness. The uncertainty in the laboratory position of this head is particularly regrettable, since a comparison of this with the comet position might shed some light on the question raised by Professor Fowler as to the existence of a high pressure spectrum of carbon monoxide in the spectrum of a comet. A fuller reference will presently be made to this phase of the subject.

As is indicated in the table, both of the D lines are present, forming a close double, D_2 being much the brighter.¹⁴ At its brightest part the stronger component overlaps its neighbor, and the proximity of one to the other renders the measurements somewhat uncertain. In view of this fact, the residuals of .7A, more or less, are not unduly large.

A word may not be out of place concerning the line at 6300A. This line is stronger than any other on the less refrangible side of D . I had photographed a line very close to this (6301A) in the gaseous nebulae,¹⁵ and it occurred to me, on what seemed to be its reappearance in the comet spectrum, that it might be the strong red aurora line which lies close to this position ($6298\text{\AA} \pm$). As has been pointed out by Dr. Campbell the green aurora line can be observed on practically every clear night, so that it did not appear impossible that the red one might record on plates, strongly sensitive in this region, during the photography of a comparatively faint spectrum—particularly with the telescope directed to the horizon. I accordingly made an all night exposure with the spectrograph pointed at the northern sky near the horizon, and as there was no record on the plate it may be assumed that the red line, and in fact all the measured radiations, belong to the comet.

The positions of a number of the Fraunhofer lines in the spectrum of the nucleus have been measured. As already noted, the C line appears to be displaced toward the violet by about $1\frac{1}{2}\text{\AA}$, probably as a result of the presence of a neighboring bright band. $H\beta$ appears on most of the plates, but I have a suspicion that it is comparatively weak. Unfortunately, on the best plates, the continuous spectrum is rather faint

¹⁴ The appearance of these lines has always been associated with a comparatively close approach to the Sun. The distance of the comet at the time of the observation was half an astronomical unit.

¹⁵ *L. O. Bulletins*, 6, 61, 1910.

TABLE V
WAVE LENGTHS IN THE SPECTRUM OF BROOKS'S COMET (1911c)

G. M. T. Oct. 22.05 Plate no. 333 Wt. = 2	Oct. 23.05 335 2	Oct. 29.05 337 2	Oct. 29.05 338 1	Nov. 1.04 341	Adopted mean	Description	Wave lengths in terrestrial sources
λ	λ	λ	λ	λ	λ		
3864	3864	3864	3864		3864	Bright line in band, fairly strong	
3869.0	3869.0	3868.5	3868.5		3868.8	Broad maximum of band, very bright	3871.54 2nd edge, 3rd CN band
3873.1	3873.1				3873.1	Bright line	3874 Strong group in 3rd CN band
3878	3878				3878	Suspect line in train of bright band	
3881.2	3881.2			3881.5	3881.2	Broad maximum of bright band, exceedingly bright	3885.55 1st edge in 3rd CN band
					3951	Suspect bright line	
					3963	Hazy bright line	
					3974	Bright line	
					3987.9	Bright line	
					3992.8	Bright line	
3992.5					4001	Long bright line (tail)	4001.3 Low pressure CO
				4003	4002	Short bright line (nucleus)	
4013.6					4013.7	Short bright line	
4019.7					4019.6	Short bright line	
				4023	4022	Long bright line (tail)	4020.4 Low pressure CO
					4033.1	Short bright line	
4040.0					4040.0	Double bright line	
4043.0					4043.0		
4051.3					4051.5	Bright line, hazy on less refrangible edge	
4069.1					4068.9	This pair of bright lines seems to extend from nucleus toward Sun	
4074.7					4074.6		
					4083	Suspect bright line	
					4089	Suspect bright line	
4099					4098.8	Bright line	
					4109	Suspect bright line	
4194				4197	(4195)	Broad hazy band; on plate no. 338 it looks double, with maxima as indi- cated in brackets	4197.24 2nd edge, 2nd CN band
					4196		
					(4202)		
4214.9				4215.1	4215.0	Long bright line (head)	4216.12 1st edge, 2nd CN band
					4230	Long bright line (tail)	
					4238.5	Long bright line (tail)	
				4255.6 $\pm$ 1	4254.5	Long bright line (tail)	4253.2 Low pressure CO
					4265	Suspect bright line	
				4277.6 $\pm$ 1	4277.2	Long bright line	4276.0 Low pressure CO
4292.2					4292.2	Narrow bright line	
4297.2					4297.4	Short bright line	
4301.2					4301.2	Narrow bright line	
4303.8					4303.8	Bright line	
4313.1					4313.2	Bright line, very short	
4329					4329	Short bright line	
4334.7					4334.8	Short bright line	
					4349	Bright line	4353 High pressure CO (?)
4364.7					4364.5	Bright line hazy on violet edge	{4365 High pressure CO (?)
4371.5					4371.3	Bright line hazy on violet edge	{4365.01 3rd edge, 5th C band
4381					4381	Bright line hazy on violet edge	4371.31 2nd edge, 5th C band
							4381.93 1st edge, 5th C band

BROOKS COMET, 1911*c*

Fig. 1

1911 October 29. Iron spark comparison. (No. 337)

Fig. 2

Composite reproduction of plates No. 333 and No. 335, 1911 October 22-23. Helium tube comparison.

Fig. 3

1911 October 5. Iron spark comparison. (No. 327)

Fig. 4

Out of focus

1911 October 29. Iron spark comparison. (No. 338)

Fig. 5

1911 November 1. Iron spark comparison. (No. 341)

BROOK'S COMET, 1911*c*

OBJECTIVE PRISM SPECTROGRAMS

Fig. 6
1911 September 14

Fig. 7
1911 September 27

388 401 427 456 506

Fig. 8
1911 October 29

388 401 427 456 506

Fig. 9
1911 November 1

The curvature of the tails results from an optical distortion introduced by the prisms.

September 27

October 18

October 20

October 21

October 25

October 24

October 27

October 31

November 2

November 3

G. M. T. Oct. 22.05 Plate no. 333 Wt. = 2	Oct. 23.05 335 2	Oct. 29.05 337 2	Oct. 29.05 338 1	Nov. 1.04 341	Adopted mean	Description	Wave lengths in terrestrial sources
λ	λ	λ	λ	λ	λ		
4672 0					4525	Long bright line (tail)	4545.4 Low pressure CO
4677.8 2	4678 2	4678.1	4526 00	4524 00	4547	Long bright line (tail)	4570.5 Low pressure CO
4684.6 2	4683.7 2	4684.3	4547.0 0	4547.4 $\pm$ 1	4572	Long bright line (tail)	4606 1st edge, 1st CN band
			4573 0	4571.2 $\pm$ 1	4608	Bright line	4663 High pressure CO (?)
4696.8 3	4697.1 3	4696.5	4607.6 $\pm$ 1		4660	Faint hazy bright line in train of band	
		4660			4672	Faint bright line	
					4678.0 ²	Long bright line	4678.8 5th edge, 4th C band
					4684.2 ²	Long bright line	4684.94 4th edge, 4th C band
4696.8 3	4697.1 3	4696.5		4691 0	4691	Long bright line (tail)	4688.5 Low pressure CO
		4705.9			4696.8	Long bright line	4697.57 3rd edge, 4th C band
4714.8 4+	4714.5 4	4714.4			4706	Suspect faint hazy bright line in band	
					4714.6	Long bright line	4715.31 2nd edge, 4th C band
		4723.1		4719 0	4719	Long bright line (tail)	4715.0 Low pressure CO
4736.6 4	4736.3 4	4736.2			4723	Suspect faint hazy bright line in band	
4745 0	4743 0	4745.4			4736.4	Long bright line	4737.18 1st edge, 4th C band
4753 0					4745	Faint bright line	
4838.0 0	4837.7 0	4837.8			4753	Suspect bright line	
4925 0	4925.7 1—				4837.8	Bright line	
5092 $\pm$	5096 1	5093			4925.5	Bright line	
5117 0					5094	Hazy line or band	5099.27 3rd edge, 3rd C band (?)
5128.3 3	5128.0 3	5127.8			5117	Faint bright line	
5164.4 5	5164.0 5	5162.7			5128.0	Bright line	5129.36 2nd edge, 3rd C band
5179 0	5177 0				5164.0	Bright line	5165.30 1st edge, 3rd C band
5418 0	5418.9 0				5178	Bright line	
5428.6 1	5427.9 0				5418.5	Bright line	
5469 0	5471 0				5428.3	Bright line	
5539.7 1	5540.3 1				5470	Hazy bright line	
5585.4 1+	5584.3 2—				5540.0	Bright line	5540.86 3rd edge, 2nd C band
5635.1 2	5634.5 2				5584.8	Bright line	5585.50 2nd edge, 2nd C band
5693 0	5692 0				5634.8	Bright line	5635.43 1st edge, 2nd C band
5706 1	5704.5 1—				5692.5	Bright line	
5732.2 0	5732 0				5705	Hazy bright line	
5779 1—					5732	Bright line	
5889.4 3	5889.5 3				5779	Bright line	
5895 1	5896.0 1+				5889.4	Bright line	
5977 1	5977 0				5895.5	Bright line	5890.2 D ₂
5995 1—	5993 0				5977	Bright line	5896.2 D ₁
6021 0	6020 0				5994	Bright line	
6300 1	6300 1				6020.5	Bright line	
6562.3	6561.1				6300	Bright line	
6578 0	6578 0				6561.7	Dark line	6563.0 H α
6597 1	6599 1				6578	Bright line or maximum	
6608					6598	Bright line or maximum	
6619 1	6619 1				6608	Minimum	
					6619	Bright line or maximum	
					6630	Minimum	

¹ There is a scratch on this negative at this point, obliterating all details.² These two heads are about equally intense.³ These lines are out of focus on this plate.

in this region, but there is no difficulty in recognizing the solar lines at 4891A, 4921A, and 4958A. In the Sun these are much weaker than $H\beta$, but on plate no. 337, taken on November 29, they seem stronger.¹⁶ A number of dark lines on this plate were measured and their positions were found to be quite in accord with the notion that they are of solar origin. Unfortunately, comparatively few of them are really suitable for this purpose, by reason of the proximity of bright lines, or on other accounts. Although the average displacements of all the measured lines agree with the theoretical displacements, in only three cases can the measures be considered significant. The lines 4144A, 4227A, and 4326A are displaced from their positions, as measured on a solar plate taken with the same apparatus, by $+0.63$, $+0.50$, and $+0.41$ Å corresponding to a rate of increase in the light path Sun-comet-Earth of $+36$ km. per second, or exactly the computed rate. The exactness of the agreement is of course accidental, but the figures may be taken to indicate the freedom of the measures from any large systematic error.

In his exceedingly valuable paper concerning comet spectra¹⁷ Professor Fowler points out the existence of a "high pressure" spectrum of carbon monoxide, and suggests that the shift of the maximum of intensity of the carbon bands toward the violet, as noted by the early observers, is due to the presence of some of the lines of this high pressure spectrum. That such a shift might be produced by the presence of carbon monoxide was claimed by Vogel on the basis of laboratory observations, but the whole question of the observed displacement of the maximum in the spectrum of a comet was clouded in obscurity until Kayser, in a paper already alluded to, showed that with a wide slit, such as is necessarily used in observing a faint spectrum visually, there must be a very large displacement of the maximum toward the more refrangible end of the spectrum. By taking any one of a number of photographs of the blue comet band, which closely resemble reproductions of the photographs of the corresponding band in the spectrum of carbon, and examining it with an eyepiece out of focus, thereby simulating, in a rough sort of way, the conditions of observation with a wide slit, the maximum appears to be in the vicinity of the fourth head, at 4684A; the general appearance of the band under these conditions calling strongly to mind Kayser's drawings of the theoretical intensity curves for wide slits.

¹⁶ It will be recalled that Dr. Campbell observed a bright line close to this position in the spectrum of Comet 1893c (*Publ. A. S. P.*, 5, 208, 1893), and suggested its possible identity with $H\beta$. It may be that the apparent weakening of the dark $H\beta$ line is produced by a feeble bright-line radiation at this point.

¹⁷ *M. N. R. A. S.*, 70, 484, 1910.

In the opinion of the writer, Kayser's theory is competent to explain all of these early visual observations of the position of maximum of the blue band, and probably of the others. A matter of interest in this connection is the relative intensity of the fourth and fifth heads of the cometary band, since the suspected monoxide line falls close to the fifth head, and would merge with it if it were present. On three of the slit spectrograms of Brooks's comet the lines stand well apart, and are, as nearly as can be estimated, of equal intensity. Kayser gives the relative laboratory intensities as 8 to 7, so there is a possibility that the fifth head is receiving assistance from the outside, but hardly enough to disturb the equilibrium of the entire band. But, while I am convinced that there is no occasion to call in the aid of carbon monoxide to explain the supposedly anomalous observations of the pioneers, I think there is little doubt that Professor Fowler's work has established a strong presumption in favor of the existence of high pressure carbon monoxide radiations in cometary spectra. His wave lengths for the series of lines as determined in the laboratory are as follows:

λ	Int.	λ	Int.
{ 6441	4	{ 5030	2
{ 6420	2	{ 5015	1
{ 5897.5	6	{ 4679	10
{ 5878	3	{ 4663	4
{ 5431	5	{ 4365	5
{ 5413	2	{ 4353	2

There can be no question that the comet line at 4365A is too bright to be due entirely to the third head of the fifth carbon band at 4365.0A. Years ago Kayser considered the identity impossible. Since his opinion was published the first two heads of this band have been observed in comets, but 4365A, the weakest of the three in the spectrum of carbon, is much the strongest in that of a comet.¹⁸ As Fowler suggests, there is a strong probability that the enhancement is due to the monoxide line at 4365A. I have observed a line on one plate at 4660A. While it is hardly likely that the wave length is in error 3 units, the line is a difficult one, being involved in the haze of the bright blue band, and it is possible that it may be Fowler's line at 4663A. There is also a comet line at 5428A, close to the monoxide line 5431A, and one at 4349A, observed as well by Plummer¹⁹ in Daniel's comet, 1907d, close to the monoxide

¹⁸ As observed with low dispersion the first head, at 4381A, seems weaker than the second, at 4372A. This is probably due to the fact that the first band partly falls in with the strong solar line at 4383.7A and is thereby apparently weakened.

¹⁹ *L. O. Bulletins*, no. 135, 5, 31, 1907.

line 4353A. It is a somewhat curious fact that these three residuals are practically the same, both in direction and amount; that is, the wave lengths given by Fowler are just 3 units greater than those measured in the comet. The possibility that we are dealing with a systematic error in one of the systems would seem to be eliminated by the close agreement between the two lines 4365A, but in this case the comet line is undoubtedly composite. Professor Fowler's wave lengths are given as provisional. In this connection it will be a matter of interest to learn his final values. The bands are spoken of as not being strictly monochromatic. It may be that we are dealing with a phenomenon similar to that involved in the apparent displacement of the maxima of the carbon bands. In addition to these suggested identities there do not seem to be any others, except possibly at 5897A, and here, as is well known, there is a conflict with D_1 .

The group of bands between 4000A and 4075A (exclusive of tail bands) are noteworthy on account of their gradual suppression, relatively to the brightness of the comet, as the Sun was approached. The coincidence of these lines with lines in the train of the second cyanogen band heading at 4216A has been pointed out, but Kayser²⁰ and others consider that these coincidences are without physical significance, as the cyanogen lines are too faint to show in the comet spectrum. Some of these cometary lines are in fact brighter than the head of the band. I am inclined to share Professor Kayser's view, not only on the

grounds on which he bases his conclusion, but also because these lines faded in Brooks's comet as the cyanogen band at 4215A increased in intensity. There was a somewhat analagous change in the spectrum of Halley's comet.

The cyanogen band at 3881A was, as is usually the case, the brightest in the spectrum. No assignment of intensity was attempted on the scale adopted for the rest of the lines. This scale runs from 0, representing a very faint line, to 5, the intensity assigned to the brightest head in the green band. Exceedingly faint and uncertain lines are given a rating 00.

For purposes of comparison with the spectra of other comets the table arranged by Dr. Campbell in *Lick Observatory Bulletins*, no. 135, 5, 31, 1907, will be found of great convenience.

Referring to Plate I, figure 2, is a composite photograph made by clamping plates no. 333 and no. 335 film to film and photographing the combination in the enlarging camera. In this way the contrast necessary for reproduction on paper was secured with a minimum loss of detail. Another advantage of this procedure is that while the lines of the spectrum are intensified some photographic defects are suppressed.

Attention has already been called to the fact that the apparently strong curvature of the tail in figures 7, 8, and 9 is almost entirely an instrumental effect, having its origin in the same causes which produce the curvature of the spectral lines in a prism spectroscope.

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²⁰ *Astronomy and Astrophysics*, 13, 206, 1894.