

The Emission Spectrum of Comet Ikeya-Seki 1965-f at Perihelion Passage*

C. D. SLAUGHTER

Kitt Peak National Observatory, Tucson, Arizona†

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Daylight observations of Comet Ikeya-Seki (1965-f) were obtained on 20 and 21 October 1965, at solar distances less than 0.2 a.u. The spectrograms obtained show many atomic and molecular emission lines within the comet head. The plates contain a combination of three spectra: (1) the above-mentioned emission lines, (2) the solar spectrum from the daylight sky, and (3) a Fraunhofer spectrum reflected from the comet. Contamination of the emission-line spectra by the reflected spectra necessitated a procedure for determining an exact representation of the two absorption spectra to permit their effective removal. The resulting emission spectrum, containing lines due to Na I, Ca I, Ca II, Cr I, Co I, Mn I, Fe I, Ni I, Cu I, V I, and CN, is catalogued in an atlas containing 477 entries. The anomalous Cu/Fe abundance found by Preston is confirmed; no evidence is found of the [O I] line at $\lambda 6300.30 \text{ \AA}$. An effective Boltzmann temperature of 4480°K is derived from the Fe I and Ni I lines, which do not exhibit marked effects of fluorescence. The violet (0,0) CN band at $\lambda 3880 \text{ \AA}$ exhibits many intensity deviations when compared to solar or laboratory reference spectra.

I. OBSERVATIONS

DAYLIGHT observations of the sun-grazing comet, Ikeya-Seki (1965-f), were obtained at the McMath Solar Telescope on 20 October 1965, just prior to perihelion passage and on 21 October, immediately after perihelion. The observations consist of 55 spectrograms of three types: (1) high-dispersion plates of the sodium *D* lines, which appear in dramatic emission (Livingston, Roddier, Spinrad, Slaughter, and Chapman 1966) and which were analyzed (Spinrad and Miner 1968) to deduce the physical structure of the comet coma and tail; (2) search plates at $1.1 \text{ mm/\AA}$ looking for such features as the $\lambda 6300.30 \text{ \AA}$ line of forbidden oxygen, lithium lines at $\lambda 6707 \text{ \AA}$, Balmer lines, and the *H* and *K* lines of Ca II which, like the sodium lines, exhibited extended structure; and (3) a map of the comet emission from $\lambda 3300$ to $6000 \text{ \AA}$ at $1.1 \text{ mm/\AA}$ covering 21 plates. This paper presents a tabulation of emission lines obtained from the spectrum map.

Table I contains a log of the spectrum map observations which were all obtained on 21 October. During these observations the comet, seen at an apparent distance of about 5° from the solar limb, appeared as a diffuse condensation 6 arc sec in diameter. No tail was visible at the focal plane of the telescope where the 0.487-arc sec/mm image scale and high sky brightness combined to reduce the contrast. A point nucleus, variably visible in the intermittently good seeing, was maintained on the slit of the spectrograph so that at least 75% of the plates show a sharp dark streak in the center of the diffuse reflected continuum. The Czerny-Turner spectrograph (Pierce 1964) produces a 1:1 transformation of the image plane onto the spectrogram so the effective image scale on the photographic plate is 0.487 arc sec/mm .

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A $100\text{-}\mu$ by 75-mm slit oriented along the sun-comet radius was used through the spectrum map observations. The comet nucleus was maintained approximately 15 mm from the near-solar end of the slit. Order sorting, between first and second orders, was achieved by selection of appropriate emulsions and/or filters: IIa-O plates in the violet, 103a-D in the green, and by a GG13 Jena filter and IIa-F plates above $\lambda 5800 \text{ \AA}$.

Three distinct spectra are represented on the plates: (1) a Fraunhofer spectrum of the daylight sky which covers the entire plate, (2) an emission line spectrum emitted within the nucleus of the comet, and (3) a weaker Fraunhofer spectrum reflected by the comet. Spectra (2) and (3) are displaced with respect to (1) by

TABLE I. Log of spectrum map observations.

Wavelength interval	IS No.	U. T. of midexposure		Exp.	Emul.	Filter
		21 Oct.	1965			
3190-3313	28	15.97		10 ^m	IIa-O	None
3303-3608	27	16.02		10 ^m	IIa-O	None
3484-3779	29	16.38		4 ^m	IIa-O	None
3677-3971	30	16.48		3 ^m	IIa-O	None
3865-4157	31	16.73		3 ^m	IIa-O	None
4061-4355	32	16.83		3 ^m	IIa-O	None
4100-4394	35	17.05		2 ^m	103a-D	None
4233-4527	33	16.90		3 ^m	IIa-O	None
4254-4550	36	17.17		2 ^m	103a-D	None
4427-4718	37	17.25		1 ^m	103a-D	None
4430-4723	34	16.93		3 ^m	IIa-O	None
4639-4930	38	17.35		40 ^s	103a-D	None
4816-5107	39	17.86		40 ^s	103a-D	None
4985-5276	40	17.88		40 ^s	103a-D	None
5200-5471	41	17.92		40 ^s	103a-D	None
5384-5675	42	17.98		40 ^s	103a-D	None
5593-5884	43	18.00		40 ^s	103a-D	None
5771-6060	44	18.03		1 ^m	103a-D	Y10
5948-6237	45	18.25		10 ^m	IIa-F	Y10
6140-6430	46	18.50		12 ^m	IIa-F	Y10
6355-6610	47	18.75		15 ^m	IIa-F	Y10

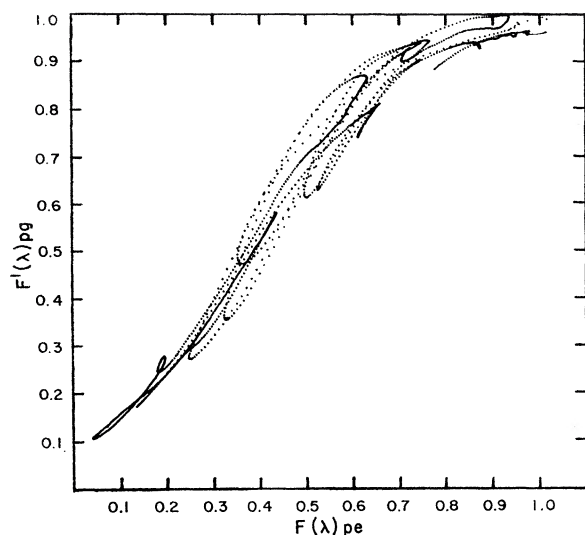


FIG. 1. Transformation function obtained from a comparison of photoelectric $F(\lambda)_{pe}$ vs photographic $F'(\lambda)_{pg}$ flux measurements of the $\lambda 4226\text{-}\text{\AA}$ region.

Doppler shifts corresponding to the respective Earth-comet and sun-comet-Earth velocity vectors. The observed intensity, $O(\lambda)$, may be considered as made up of a comet emission, $E(\lambda)$, convolved with two versions of a solar flux spectrum, $F(\lambda)$,

$$O(\lambda) = E(\lambda) + C_1 F(\lambda + \Delta_1 \lambda) + C_2 F(\lambda + \Delta_2 \lambda).$$

No accurate measurement of the emission lines was possible without completely disentangling the three spectra. Moreover, weak features were undetected until the contaminants were extracted. Problems with calibration control made it difficult to duplicate the sky spectrum, consequently it was taken from the antisolar edge of the comet plates. Measurements of the density distribution across the coma determined that the detectable central condensation was less than 30 arc sec, except at the positions of Na I and Ca II whose emission structures extend across the plates.

II. REDUCTION OF THE PLATES

A. Plate Calibration and Microphotometry

Three calibration plates, one each of the three types used in the observations, were taken late on 21 October. These proved, as did several of the comet spectrograms, to be poorly exposed for the emission-line intensity. These plates were exposed for an adequate density in the continuum of the scattered light spectrum and the range in density did not include the strongest emission lines. Additional calibration procedures were used to investigate possible errors in the representation of strong emission lines and to extend the spectral range of the calibration plates.

Photoelectric observations of the solar spectrum augmented the calibrations by extending the spectral range. Six wavelength regions, two in the range of each type of emulsion, were observed under conditions duplicating the solar illumination on 21 October. These observations of strong absorption lines provided a set of "standard" $F(\lambda)_{pe}$ functions to use in deriving trans-

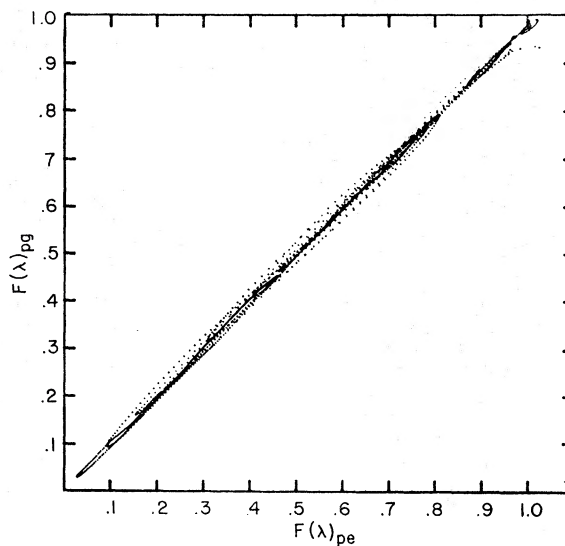


FIG. 2. Comparison of $F(\lambda)$ measurements taken from a photographic plate calibrated by photoelectric data vs that obtained from a usual photographic step-wedge calibration, $F(\lambda)_{pg}$.

formations from photographic density to the desired flux representation. To facilitate derivation of a transformation function, the photographic density curve was converted into a pseudoflux form $F'(\lambda)_{pg}$ by taking its logarithm. Figure 1 shows the form of the transfer function obtained by dividing $F(\lambda)_{pe}$ by $F'(\lambda)_{pg}$ for the $\lambda 4226\text{-}\text{\AA}$ region. Figure 2 illustrates the comparison between $F(\lambda)$ derived from a spectrogram by the above transformation and that obtained from a conventional step-wedge transformation.

A linear extrapolation of the slope of the transfer function was used to extend the dynamic range. The accuracy of intensities derived for strong emission lines by this means was evaluated by simulating the observed comet spectrum. This was done by taking a plate of the Fraunhofer spectrum and superimposing a thorium emission-line spectrum. The resulting densities in the strongest thorium lines saturated the photographic plate. Intensities of the strong lines were derived from a linear extrapolation of the slope of the photoelectric transfer function. They agreed with photoelectric measurements of the same lines to within a factor of 2 in intensity at a density of 1000. Figure 3 illustrates the photographic vs photoelectric measurement of the thorium spectrum. Scatter in points at low density

arises from an inaccurate representation of the underlying solar spectrum. At a risk of overestimating intensities of stronger emission lines, the transfer functions derived from photoelectric observations were utilized with linearly extended range.

A careful examination of the five strongest emission lines, excepting Na I, produced profiles of the same shape—that of the instrumental profile. This consequence of wide spectrograph slits (100μ) permitted microphotometer digitization using a $50\text{-}\mu$ analyzing slit. The plates were sampled at a spectral interval of $0.012\text{ \AA}/\text{step}$, twice as many points as were required, to facilitate later reduction procedures. Each plate was measured at six positions using a 1-mm high slit, four

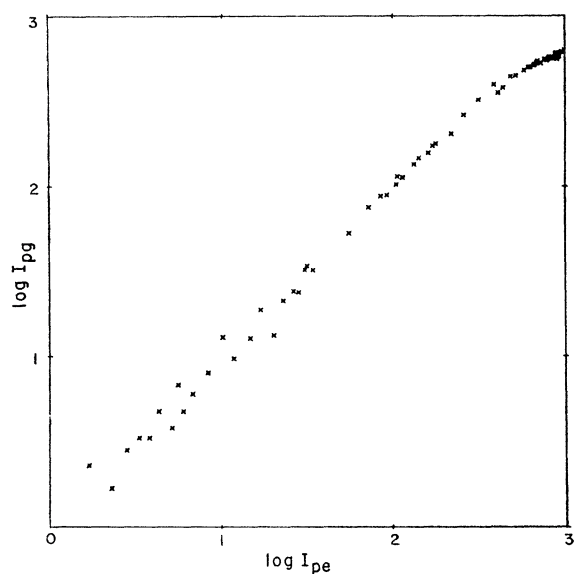


FIG. 3. Log intensity of thorium emission lines used as an intermediate step in the calibration: Measures by photoelectric photometry I_{pe} compared to the same lines measured by photographic photometry I_{pg} .

locations covering the comet head, and two at displacements of 30 and 42 mm from the head. Scans across the comet head were made at the center of the density distribution, 1.3 mm toward the sun, 1 and 2 mm away from the sun. The sky scans were somewhat variable in position to obtain the cleanest scans within 2 mm of the stated displacement.

B. Deconvolution

Initial attempts at deconvolution utilized measured wavelength displacements $\Delta\lambda$ and an estimated fixed ratio of C_2/C_1 . It was found that several iterations were required to determine the proper value of C_1 . Also this first effort showed that the variation in $\Delta\lambda$ with λ of $152\text{ m\AA}$ over a $250\text{-\AA}$ plate required dividing each plate

into eight separate $50\text{-\AA}$ parts. A better reduction method was found which consisted of deriving the shifting and scaling parameters from a deconvolution of the composite spectrum by the sky spectrum. This procedure produces two delta functions representing the relative strengths of the two scattered light spectra, and the distance between the delta functions indicates the relative wavelength displacement of these spectra. The zero point in the displacement scale and the magnitude of C_1 are derived from a self deconvolution of the sky spectrum. Figure 4 shows the convolving profile and the autoconvolution function in a typical case. Both curves are smoothed by a Gaussian function to suppress the effect of noise in evaluating the constants for each spectral interval.

Two sky spectra, appropriately scaled and displaced to match their representation in the combined comet spectrum, are subtracted from the composite. Figure 5(a), (b), (c) illustrates the deconvolution resulting in Fig. 5(d) which shows the emission and residual noise for a typical wavelength interval.

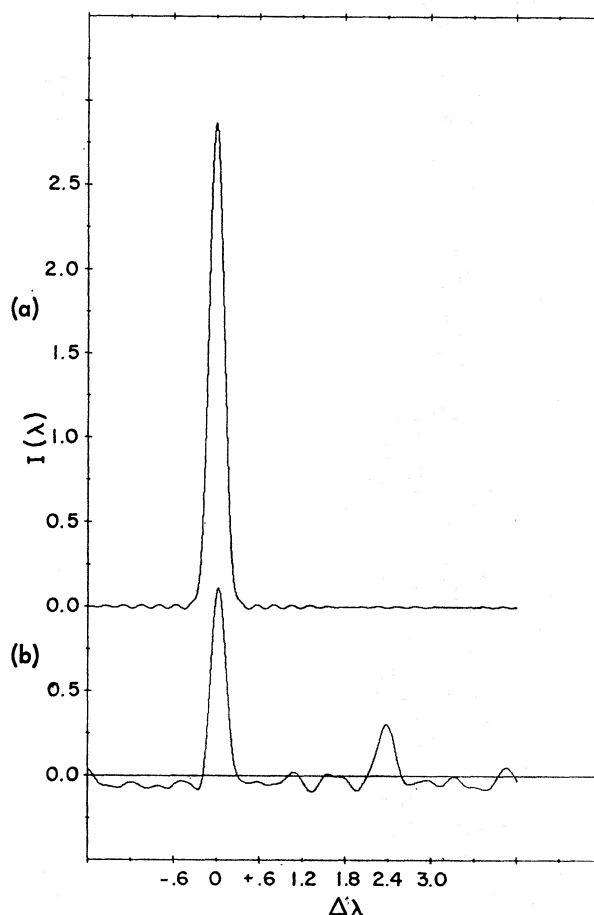


FIG. 4. Constants used in deconvolving the observed comet are derived from a comparison of the autoconvolution of the sky spectrum (a) to a comet sky deconvolution (b).

C. Equivalent Widths, Wavelengths, and Errors

Prior to evaluating C_1 and C_2 , the sky spectrum is normalized to a continuum level appropriate to the wavelength region, as determined by the *Utrecht Atlas* (Minnaert *et al.* 1940) or the *Brückner Atlas* (Brückner 1960). Consequently, the emission lines are scaled so their area is directly proportional to their equivalent width in units of the local scattered skylight continuum.

Each emission-line spectra scan is differentiated twice and from zero crossings of the second derivative the strength and position of each line is derived. In practice this is done by creating a model of the expected emission line shape and comparing with the observed lines. The model is made up of the convolution of a $100\text{-}\mu$ slit with a $50\text{-}\mu$ slit, which yields a second derivative having four zero crossings. The middle pair determines the inflection points in the line profile whose separation measures the width at half maximum. By scaling the model line, until the widths equal those obtained from the data, an internally consistent set of intensities is obtained. This process is capable of representing the intensities of moderately blended lines. A selected set of these lines was integrated over wavelength to obtain a width to

equivalent-width conversion scale which was applied to all the measured lines.

Relative positions of emission lines within one wavelength region are taken from the zero crossings of the first derivative where they exist; otherwise the mid-points in the second derivative are used to locate the lines. A wavelength scale is applied to the resulting measurements by identifying one of the stronger emission features and assigning to it the wavelength specified in the *Second Revision of Rowland's Preliminary Table of Solar Wavelengths* (Moore *et al.* 1966). Wavelengths of the remaining features within the region are derived by applying the grating equation with constants appropriate to the instruments.

Internal probable errors in the intensity are determined from lines observed on more than one spectrogram. Figure 6 illustrates the internal error as a function of line strength. Wavelength accuracy is established in a

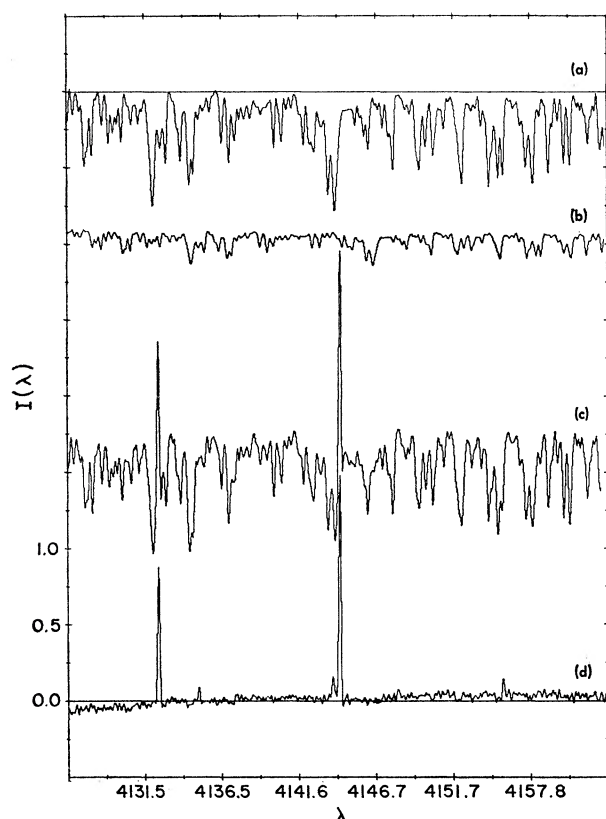


FIG. 5. Illustrated is the sky spectrum: (a) normalized to unit continuum level and reflected Fraunhofer spectrum, (b) subtracted from observed composite, (c) to yield the comet emission spectrum (d).

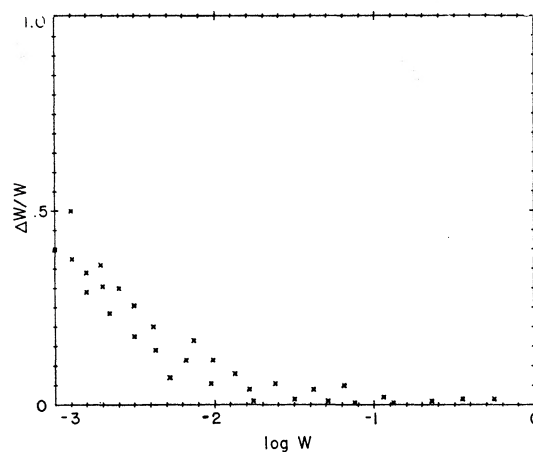


FIG. 6. Probable error in equivalent width of cometary emission lines as a function of equivalent width.

similar manner, utilizing only atomic lines of a strength which would qualify for minimal intensity error.

III. THE ATOMIC SPECTRUM

A plot of excitation potential of the upper level, taken from *A Multiplet Table of Astrophysical Interest* (Moore 1959), against $\log(I\lambda^3/gf)$ for all the Fe I lines is shown in Fig. 7. A formal excitation temperature of 4480°K is derived from a least-squares fit to

$$\log \frac{I\lambda^3}{gf} = C - \theta\chi,$$

which yields $\theta = 1.12 \pm 0.08$. This is in agreement with the previous determination of Preston (1967) who found

an excitation temperature of 4500°K. The apparent scatter of points in Fig. 7 occurs primarily in weak lines but is uniformly distributed about the mean. A similar curve for the Ni I lines shows a higher scatter, and gives $\theta = 1.14 \pm 0.11$ in excellent agreement with the iron lines.

Many weak lines were observed at wavelengths ascribed to Co I, particularly multiplets 19 through 25,

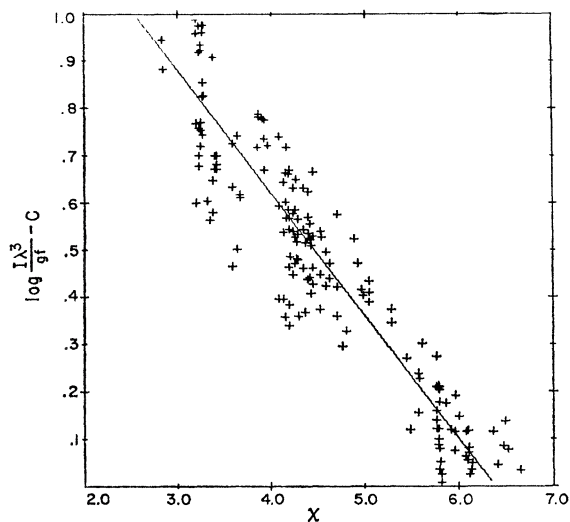


FIG. 7. The curve of growth derived from Fe I corrected emission intensities: The least-squares line gives an excitation temperature of 4480°K.

and have been so identified in the atlas. An energetic search for lines of Mg I, Al I, Si I, and Ti I proved fruitless, but the *Raie Ultime* of V I at $\lambda 4379.238$ was found. None of the subsequent strong lines in the multiplet were detected. Abundance estimates, or upper limits as the case may be, for lines of these elements will require careful study as their intensities are modified strongly by the incident solar spectrum.

The anomalously high intensity recorded for the Cu I lines of multiplet 1 is probably due to an improper setting of the continuum level and hence the intensity scale in the ultraviolet. The abundance of copper relative to iron, derived on the assumption of a Boltzmann distribution with $\theta = 1.12$, is even higher than that obtained by Preston. The lines of multiplet 1 yield

$$\log [N(\text{Cu I})/N(\text{Fe I})] = +0.1.$$

On the other hand, the abundance derived from the single line of multiplet 2 at $\lambda 5105.545$ Å gives

$$\log [N(\text{Cu I})/N(\text{Fe I})] = -0.6,$$

which is more reasonable although still high compared to the solar value.

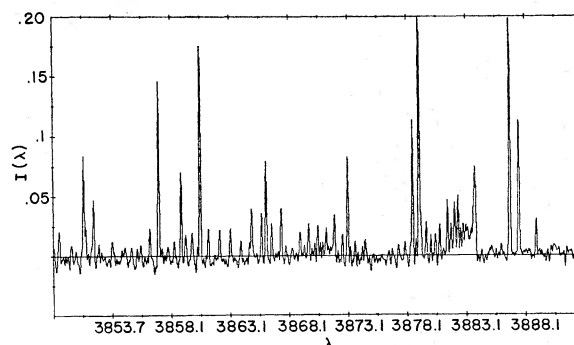


FIG. 8. CN emission spectrum of Comet Ikeya-Seki showing the (0,0) P band head and R branch to R33 after correcting for the reflected Fraunhofer spectrum and sky light.

Intensity estimates for the sodium *D* lines are not included as no simple equivalent widths would accurately describe their appearance. Those interested in a discussion of these lines are referred to the work by Spinrad and Miner (1968).

IV. THE MOLECULAR SPECTRUM

The violet CN system is represented in the strong (0,0) band by lines out to R33. The (1,1) band is weakly represented by transitions to R21. Figure 8 illustrates the violet CN system. Crowding of emission lines in the region $\lambda\lambda 3850-3884$ is possibly responsible for an apparently systematic shift of the CN lines with respect to the local Fe I emission. This +20-mÅ shift has persisted through all the various reductions and may well be real.

Most intensity anomalies are due to line structure in the exciting solar radiation field. Some lines which are not perturbed (Kiess and Broida 1961) appear exceptionally strong, an effect which is difficult to explain unless one assumes an enhancement of selected transitions by radiation field anomalies.

A few weak lines lie near positions associated with CH transitions, but they are so tenuous that no association has been made.

V. EXPLANATION OF THE ATLAS

The atlas (Table II) lists the observed wavelength, and intensity at four positions across the comet, of 477 emission lines. All observed lines have been grouped together in order of increasing wavelength, which is contained in column 1. Column 2 lists the wavelength of the solar identification, if any, contained in column 3. The RMT multiplet number and solar intensity are given in columns 4 and 5. The last columns contain the equivalent width derived for each line at four positions across the comet head.

The position of each determination is indicated in the column heading. This is given as a displacement, in

TABLE II. Atlas: Observed wavelength and intensity of 477 emission lines.

Observed wavelength	Solar wavelength	Identification			Observed intensity			
		RMT No.		Int.	Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
3208.233	3208.214	CU I	3	10	19	14	9	3
3214.395	3214.402	FE I	7	105	29	19	7	8
3221.679	3221.659	NI I	8	104	27	12	3	0
3225.028	3225.031	NI I	39	125	30	18	9	6
3227.755	3227.752	CO I	8		5	0	0	0
3232.938	3232.938	NI I	7	214	125	78	70	68
3234.628	3234.647	NI I	21	109	11	11	3	0
3236.232	3236.232	FE I	7	47	29	15	8	5
3243.088	3243.071	NI I	22	157	75	44	23	18
3245.734					11	12	0	0
3246.049	3246.031	FE I	8	111	14	8	4	0
3247.569	3247.569	CU I	1	246	402	249	254	150
3248.525					4	2	0	0
3250.776	3250.767	NI I	39	114	12	4	2	0
3265.621	3265.640	FE I	91	102	36	14	10	9
3271.019	3271.006	FE I	91	172	34	19	8	7
3273.972	3273.972	CU I	1	221	220	143	120	83
3277.370					9	5	0	0
3286.778	3286.772	FE I	91	660	61	34	18	14
3320.262	3320.262	NI I	9	122	17	14	8	2
3322.315	3322.325	NI I	39	108	10	2	0	0
3329.630					15	11	0	0
3331.751	3331.785	FE I	144	48	5	2	0	0
3333.783					6	3	1	0
3361.566	3361.570	NI I	19	90	13	8	4	2
3365.772	3365.773	NI I	38	107	27	17	7	0
3366.168	3366.176	NI I	8	116	57	25	13	5
3369.578	3369.578	NI I	6	407	97	62	33	25
3372.004	3372.089	FE I	83	118	44	25	8	9
3374.227	3374.222	NI I	17	150	28	19	5	6
3380.579	3380.585	NI I	37	809	61	41	26	17
3380.901	3380.889	NI I	7	87	15	11	3	0
3384.028					10	9	1	3
3388.183	3388.175	CO I	23	103	11	8	0	0
3391.054	3391.039	NI I	5	238	96	59	30	16
3392.665	3392.624	FE I	85	144	3	0	0	0
3393.001	3392.978	NI I	20	570	140	89	56	35
3395.390	3395.386	CO I	25	111	9	3	0	0
3399.355	3399.355	FE I	85	159	17	12	7	2
3401.528	3401.530	FE I	26	104	14	16	0	5
3402.294					14	8	0	0
3404.386	3404.378	FE I	83	176	18	12	6	3
3405.142	3405.126	CO I	23	206	27	23	10	3
3406.804	3406.810	FE I	85	136	10	3	0	0
3407.498	3407.464	FE I	83	248	58	40	22	10
3409.218	3409.214	FE I	614	134	11	7	1	0
3412.348	3412.349	CO I	25	123	37	29	7	0
3412.641	3412.643	CO I	6	108	11	5	2	0
3413.140	3413.143	FE I	85	156	31	15	8	0
3413.490	3413.492	NI I	5	160	37	28	9	3

TABLE II (*continued*)

Observed wavelength	Solar wavelength	Identification			Observed intensity			
			RMT No.	Int.	Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
3413.946	3413.947	NI I	17	112	21	10	3	1
3414.775	3414.779	NI I	19	816	248	169	145	75
3417.190	3417.169	CO I	23	121	17	22	11	4
3417.879	3417.870	FE I	81	139	19	17	7	0
3418.520	3418.522	FE I	81	111	14	15	7	0
3420.740	3420.748	NI I	9	84	5	0	0	0
3422.675	3422.661	FE I	85	65	22	13	10	5
3423.725	3423.715	NI I	20	366	134	89	59	33
3424.304	3424.299	FE I	81	128	21	21	18	5
3426.421					14	8	0	0
3426.624	3426.635	FE I	82	121	8	4	0	0
3427.134	3427.129	FE I	81	218	84	55	30	13
3431.605					5	6	0	0
3433.076	3433.048	CO I	23	111	3	0	0	0
3433.579	3433.579	NI I	19	492	100	63	51	22
3437.303	3437.291	NI I	3	184	72	43	26	7
3440.627	3440.626	FE I	6	1243	135	89	79	46
3441.011	3441.019	FE I	6	634	164	108	98	54
3443.685	3443.655	CO I	22	141	9	5	0	0
3443.899	3443.884	FE I	6	655	68	43	34	16
3445.140	3445.125	FE I	81	137	30	16	12	1
3446.285	3446.271	NI I	20	470	152	101	82	42
3447.285	3447.285	FE I	82	100	8	8	5	0
3449.181	3449.175	CO I	22	115	9	6	0	0
3449.444	3449.448	CO I	22	138	12	9	2	0
3450.330	3450.334	FE I	82	97	13	6	0	0
3452.287	3452.284	FE I	25	151	15	11	6	2
3452.906	3452.905	NI I	17	247	147	105	53	37
3453.516	3453.512	CO I	22	310	91	49	31	7
3458.463	3458.467	NI I	19	656	199	138	95	59
3461.663	3461.667	NI I	17	758	180	121	86	54
3462.813	3462.816	CO I	23	126	19	16	6	4
3465.189					8	5	2	0
3465.862	3465.880	FE I	6	544	137	93	62	40
3467.512	3467.509	NI I	3	96	9	8	6	30
3469.508	3469.493	NI I	8	180	20	13	7	3
3472.558	3472.558	NI I	20	374	147	93	56	35
3474.043	3473.969	CO I	23	27	26	14	7	2
3475.452	3475.457	FE I	6	622	263	164	119	75
3476.722	3476.712	FE I	6	465	89	53	32	16
3483.786	3483.784	NI I	6	198	88	48	25	23
3489.402	3489.407	CO I	36	135	29	12	5	0
3490.602	3490.594	FE I	6	830	140	97	94	43
3492.957	3492.975	NI I	18	826	119	68	52	26
3495.280	3495.284	FE I	238	116	9	3	0	0
3495.690	3495.663	CO I	22	138	15	8	0	0
3497.116	3497.102	FE I	78	166	19	8	0	0
3497.843	3497.843	FE I	6	726	160	86	60	28
3500.858	3500.857	NI I	6	163	70	40	15	10
3502.295	3502.291	CO I	7	111	58	34	18	5

TABLE II (*continued*)

Observed wavelength	Solar wavelength	Identification			Observed intensity			
		RMT No.	Int.		Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
3502.615					12	9	3	1
3506.322	3506.328	CO I 21	140		36	19	5	2
3507.726	3507.698	NI I 3	80		14	9	0	3
3509.842	3509.853	CO I 22	105		18	10	6	2
3510.334	3510.327	NI I 18	489		77	53	21	17
3512.648	3512.646	CO I 21	132		15	6	0	0
3513.480	3513.483	CO I 5	98		11	0	0	0
3513.829	3513.825	FE I 24	307		127	70	44	24
3515.063	3515.066	NI I 19	718		201	134	102	65
3519.774	3519.764	NI I 5	171		54	29	8	6
3520.082	3520.088	CO I 4	114		6	3	1	0
3521.274	3521.270	FE I 24	381		146	80	50	30
3521.585	3521.546	CO I 20	109		9	4	1	1
3523.457	3523.444	NI I 16	96		13	11	0	2
3524.536	3524.536	NI I 18	1271		268	181	186	101
3526.057	3526.042	FE I 6	84		123	64	39	12
3526.856	3526.847	CO I 4	209		35	18	5	3
3527.979	3527.992	NI I 6	87		9	5	0	0
3529.039	3529.040	CO I 5	76		27	21	5	3
3529.822	3529.823	FE I 326	148		40	30	16	4
3533.361	3533.364	CO I 5	72		4	2	1	0
3548.191	3548.190	NI I 3	139		27	19	5	0
3551.535	3551.533	NI I 5	94		4	2	0	0
3554.119	3554.122	FE I 23	127		12	8	2	0
3558.533	3558.532	FE I 24	485		106	67	43	27
3565.398	3565.396	FE I 24	990		287	200	162	115
3566.394	3566.383	NI I 36	458		156	114	72	59
3569.383	3569.384	CO I 35	116		35	25	9	1
3570.118	3570.134	FE I 24	1380		300	210	199	128
3571.875	3571.875	NI I 5	237		71	47	30	21
3575.378	3575.374	CO I 4	115		11	8	4	0
3578.703	3578.693	CR I 4	488		23	10	11	2
3581.209	3581.209	FE I 23	2144		361	237	250	131
3584.672	3581.665	FE I 295	36		14	9	14	6
3584.976	3584.965	FE I 395	78		7	3	4	0
3585.331	3585.339	FE I 23	839		154	90	74	30
3585.716	3585.714	FE I 23	168		125	65	58	26
3586.108	3586.118	FE I 611	122		13	8	2	0
3587.005	3586.990	FE I 23	532		119	73	59	30
3587.964					8	2	0	0
3589.112	3589.112	FE I 23	104		17	6	5	0
3593.488	3593.495	CR I 4	436		46	26	10	7
3594.875	3594.876	CO I 4	92		7	5	3	1
3597.712	3597.712	NI I 18	181		58	37	20	10
3602.289	3602.287	NI I 3	94		11	8	2	0
3603.211	3603.210	FE I 295	119		23	10	8	0
3605.338	3605.339	CR I 4	495		90	61	48	41
3606.692	3606.694	FE I 294	271		88	51	50	37
3608.863	3608.869	FE I 23	1046		261	184	157	94
3609.311	3609.328	NI I 16	69		15	10	4	0

TABLE II (continued)

Observed wavelength	Solar wavelength	Identification			Observed intensity			
		RMT No.	Int.		Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
3610.472	3610.460	NI I 18	250		104	73	59	29
3612.747	3612.744	NI I 6	160		51	43	25	6
3617.792	3617.796	FE I 496	124		29	18	16	6
3618.776	3618.777	FE I 23	1410		329	238	207	124
3619.400	3619.400	NI I 35	568		215	155	125	69
3621.481	3621.467	FE I 294	140		20	10	11	2
3622.024	3622.009	FE I 295	127		21	19	13	3
3623.192	3623.192	FE I 180	105		20	13	13	2
3624.733	3624.733	NI I 2	132		36	28	17	2
3627.797	3627.813	CO I 19	98		4	1	0	0
3631.471	3631.475	FE I 23	1364		368	252	226	137
3632.057	3632.049	FE I 496	117		5	3	0	0
3636.150	3636.166	FE I 77	132		4	1	0	0
3638.302	3638.304	FE I 294	153		4	3	0	0
3640.394	3640.394	FE I 295	132		45	28	25	6
3647.842	3647.851	FE I 23	970		294	185	193	90
3649.508	3649.511	FE I 291	134		10	8	2	0
3650.334					8	11	10	5
3651.460	3651.474	FE I 295	136		22	12	11	1
3664.091	3664.097	NI I 4	130		6	3	0	0
3669.526	3669.526	FE I 291	120		26	15	13	3
3670.416	3670.431	NI I 4	120		4	1	0	0
3674.123					13	11	4	2
3676.345	3676.322	FE I 228	102		4	2	0	0
3677.637	3677.628	FE I 291	147		30	15	14	3
3679.913	3679.923	FE I 5	448		92	57	49	27
3683.054	3683.045	CO I 99	166		46	23	21	11
3684.122	3684.123	FE I 292	129		13	7	7	5
3687.466	3687.466	FE I 21	564		146	81	71	31
3688.405	3688.419	NI I 5	134		7	2	0	0
3703.545	3703.545	FE I	114		8	4	0	0
3704.467	3704.469	FE I 290	98		10	6	1	0
3705.571	3705.577	FE I 5	562		93	58	58	26
3707.842	3707.826	FE I 5	88		59	36	29	9
3709.256	3709.256	FE I 21	573		259	158	124	73
3715.921	3715.916	FE I 124	80		5	4	1	0
3719.947	3719.947	FE I 5	1664		439	316	366	197
3722.583	3722.588	FE I 5	694		181	112	98	51
3724.385	3724.385	FE I 124	124		18	10	5	2
3727.639	3727.634	FE I 21	632		228	132	115	63
3732.390	3732.406	FE I 76	142		13	11	5	0
3733.329	3733.330	FE I 5	228		134	84	72	40
3734.873	3734.874	FE I 21	3027		301	193	210	99
3737.137	3737.141	FE I 5	1071		175	119	125	69
3738.294	3738.312	FE I 609	136		12	9	8	2
3743.368	3743.368	FE I 21	592		184	104	90	43
3745.571	3745.574	FE I 5	1202		145	86	105	40
3745.914	3745.910	FE I 5	540		148	95	83	51
3748.270	3748.271	FE I 5	497		229	142	135	75
3748.951	3748.966	FE I 386	103		5	2	0	0

TABLE II (*continued*)

Observed wavelength	Solar wavelength	Identification			Observed intensity			
			RMT No.	Int.	Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
3749.496	3749.495	FE I	21	1907	267	188	200	120
3753.621	3753.620	FE I	73	132	6	2	0	0
3758.247	3758.245	FE I	21	1647	406	262	258	146
3759.835					12	8	2	0
3763.800	3763.803	FE I	21	829	306	195	182	108
3767.204	3767.204	FE I	21	820	313	196	167	94
3775.586	3775.578	NI I	33	144	53	23	29	11
3776.482					4	2	0	0
3783.544	3783.535	NI I	30	164	89	48	43	34
3785.955	3785.952	FE I	177	122	12	4	1	3
3786.688	3786.682	FE I	22	132	12	7	2	2
3787.898	3787.891	FE I	21	512	242	124	116	50
3790.090	3790.098	FE I	22	179	51	19	22	6
3795.013	3795.012	FE I	21	547	296	147	150	60
3796.665					8	6	5	3
3798.512	3798.521	FE I	21	304	156	67	66	20
3799.548	3799.558	FE I	21	622	174	90	87	31
3805.349	3805.349	FE I	608	171	50	29	21	9
3806.690	3806.718	FE I	607	209	41	32	27	13
3807.147	3807.151	NI I	33	193	98	54	39	10
3808.043					5	2	0	0
3812.977	3812.962	FE I	22	322	163	95	82	42
3814.532	3814.521	FE I	22	170	8	4	0	0
3815.847	3815.851	FE I	45	1272	241	165	142	91
3816.313	3816.345	FE I	73	100	15	11	6	2
3820.426	3820.436	FE I	20	1712	263	170	150	90
3821.183	3821.187	FE I	608	93	35	18	11	4
3823.510	3823.514	MN I	6	116	10	8	3	2
3824.447	3824.452	FE I	4	519	157	109	109	70
3825.883	3825.891	FE I	20	1519	223	143	159	75
3826.710					7	5	1	0
3827.832	3827.832	FE I	45	897	62	42	37	24
3829.366					4	0	0	0
3833.301	3833.317	FE I	221	53	10	9	8	0
3834.226	3834.233	FE I	20	624	148	106	84	59
3839.280	3839.263	FE I	529	104	14	8	3	0
3840.448	3840.447	FE I	20	567	92	62	45	18
3841.058	3841.058	FE I	45	517	113	74	60	27
3844.237	3844.237	CN	R33	0.0	19	16	15	6
3845.476	3845.470	CO I	34	135	49	31	13	8
3846.000	3845.993	CN	R21	1.1	9	9	5	1
3847.460					15	9	7	3
3847.889					32	22	16	8
3848.940	3849.006	CN	R29	0.0	20	12	8	1
3849.328					9	7	5	4
3849.978	3849.977	FE I	20	608	100	57	36	15
3850.147	3850.165	CN	R28	0.0	17	12	8	2
3850.817	3850.826	FE I	22	222	65	40	29	12
3851.280	3851.291	CN	R27	0.0	16	14	7	0
3851.521	3851.536	CN	R15	1.1	7	5	2	0

TABLE II (continued)

Observed wavelength	Solar wavelength	Identification			Observed intensity			
			RMT No.	Int.	Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
3852.419	3852.407	CN	R14	1.1	23	17	8	2
3853.259	3853.203	CN	R13	1.1	13	9	3	0
3853.503	3853.483	CN	R25	0.0	9	7	1	0
3854.074	3854.059	CN	R12	1.1	18	16	6	2
3854.556	3854.571	CN	R24	0.0	9	8	4	1
3854.867	3854.854	CN	R11	1.1	16	9	6	0
3855.627	3855.631	CN	R10	1.1	29	14	10	4
3856.374	3856.381	FE I	4	648	160	121	79	45
3856.665	3856.664	CN	R22	0.0	8	2	0	0
3857.160					21	14	9	1
3857.717	3857.667	CN	R21	0.0	19	8	5	3
3858.293	3858.303	NI I	32	202	78	46	28	15
3858.683	3858.689	CN	R20	0.0	30	19	10	2
3859.236					34	17	11	4
3859.692	3859.668	CN	R19	0.0	12	5	3	0
3859.916	3859.922	FE I	4	1554	210	154	155	101
3860.631	3860.626	CN	R18	0.0	31	26	13	3
3861.587	3861.600	CN	R17	0.0	31	24	15	2
3862.502	3862.494	CN	R16	0.0	30	21	11	4
3863.397	3863.401	CN	R15	0.0	18	10	5	1
3864.118	3864.111	CN	P2	1.1	6	2	0	0
3864.299	3864.305	CN	R14	0.0	55	31	15	5
3865.149	3865.151	CN	R13	0.0	44	23	12	8
3865.530	3865.533	FE I	20	377	93	48	28	15
3866.002	3865.990	CN	R12	0.0	36	18	8	2
3866.818	3866.826	CN	R11	0.0	53	33	19	8
3867.213					13	5	0	2
3867.788	3867.627	CN	R10	0.0	19	6	0	0
3868.437	3868.409	CN	R9	0.0	33	17	6	7
3868.820	3868.808	CN	P13	1.1	9	5	1	0
3869.156	3869.173	CN	R8	0.0	40	25	11	6
3869.435	3869.403	CN	P15	1.1	7	3	0	0
3869.694	3869.672	CN	P16	1.1	10	6	1	0
3869.941	3869.922	CN	R7	0.0	45	31	11	4
3870.163	3870.159	CN	P18	1.1	11	7	2	0
3870.375	3870.365	CN	P19	1.1	16	7	5	4
3870.674	3870.664	CN	R6	0.0	21	12	3	0
3871.366	3871.392	CN	R5	0.0	51	31	20	14
3871.671					7	3	0	0
3872.061	3872.062	CN	R4	0.0	24	16	6	1
3872.510	3872.510	FE I	20	612	100	54	33	12
3872.718	3872.732	CN	R3	0.0	10	5	2	2
3873.122					17	5	0	0
3873.372	3873.371	CN	R2	0.0	5	1	0	1
3873.776					11	3	0	0
3873.985					23	8	0	1
3874.604	3874.573	CN	R0	0.0	2	0	0	0
3875.989					5	2	0	0
3876.299	3876.310	CN	P2	0.0	7	5	1	0
3876.840	3876.845	CN	P3	0.0	11	7	1	0

TABLE II (*continued*)

Observed wavelength	Solar wavelength	Identification			Observed intensity			
		RMT No.	Int.		Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
3877.384	3877.344	CN P4	0.0		14	9	1	0
3877.842	3877.835	CN P5	0.0		17	11	3	0
3878.028	3878.027	FE I 20	555		80	43	28	19
3878.311	3878.302	CN P6	0.0		18	8	3	2
3878.583	3878.580	FE I 4	724		312	223	140	104
3879.179	3879.194	CN P8	0.0		33	23	12	4
3879.589	3879.576	CN P9	0.0		18	15	4	0
3879.966	3879.964	CN P10	0.0		23	16	5	7
3880.333	3880.327	CN P11	0.0		27	15	6	0
3880.654	3880.677	CN P12	0.0		5	3	0	0
3880.992	3881.002	CN P13	0.0		55	46	22	7
3881.308	3881.307	CN P14	0.0		26	10	2	0
3881.593	3881.591	CN P15	0.0		48	23	8	2
3881.867	3881.875	CN P16	0.0		68	40	24	7
3882.099	3882.085	CN P17	0.0		13	7	2	0
3882.316	3882.300	CN P18	0.0		20	11	4	1
3882.533		CN P19	0.0		10	9	5	1
3882.932		CN			12	9	2	4
3883.320		CN HEAD	0.0		168	121	80	57
3885.545					11	6	3	2
3886.293	3886.294	FE I 4	920		212	157	114	79
3887.050	3887.059	FE I 20	219		134	85	51	26
3888.518	3888.524	FE I 45	265		34	24	17	5
3889.512					10	5	0	0
3892.929					11	5	3	1
3893.371					10	4	0	2
3894.059					16	11	5	1
3895.667	3895.667	FE I 4	361		218	151	92	58
3897.982	3898.014	FE I 20	158		17	8	5	1
3899.717	3899.719	FE I 4	436		185	131	83	54
3902.960	3902.956	FE I 45	530		152	98	60	28
3906.494	3906.490	FE I 4	164		112	74	49	24
3917.189	3917.184	FE I 20	151		32	16	13	8
3920.267	3920.269	FE I 4	341		212	141	90	56
3922.926	3922.923	FE I 4	414		162	113	77	46
3927.928	3927.933	FE I 4	187		190	131	77	54
3930.308	3930.308	FE I 4	108		195	132	82	47
3933.674	3933.682	CA II 1	20253		126	111	96	86
3937.623					32	11	0	0
3938.369					10	6	0	0
3940.908	3940.890	FE I 20	84		6	4	3	0
3950.039					14	8	6	2
3956.700	3956.686	FE I 278	133		31	25	17	21
3968.501	3968.492	CA II 1	15467		100	87	69	59
3969.291	3969.268	FE I 43	52		119	89	64	47
3970.937					8	6	2	0
3975.764					5	1	5	2
3977.750	3977.747	FE I 72	104		14	14	4	0
3995.301	3995.315	CO I 31	146		11	12	1	0
3997.387					13	14	3	4

TABLE II (continued)

Observed wavelength	Solar wavelength	Identification		Observed intensity			
		RMT No.	Int.	Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
3998.041	3998.058	FE I 276	115	9	4	0	0
4005.254	4005.254	FE I 43	416	150	96	57	36
4009.725	4009.714	FE I 72	122	14	8	4	0
4030.763	4030.763	MN I 2	326	165	77	56	21
4033.079	4033.072	MN I 2	229	90	43	33	9
4034.490	4034.492	MN I 2	213	84	41	29	13
4035.738	4035.732	MN I 5	216	12	8	9	4
4041.366	4041.374	MN I 5	168	34	17	16	6
4045.824	4045.825	FE I 43	1174	325	227	173	103
4048.769	4048.753	MN I 5	138	9	8	2	5
4055.550	4055.551	MN I 5	114	10	10	7	0
4058.902	4058.931	MN I 5	89	6	8	4	3
4063.605	4063.605	FE I 43	787	261	175	129	70
4071.752	4071.749	FE I 43	723	283	184	130	70
4082.976	4082.943	MN I 5	94	16	12	2	0
4083.639	4083.630	MN I 5	181	12	9	3	1
4107.524				7	6	5	5
4118.560				9	4	2	0
4121.330	4121.325	CO I 28	125	24	15	12	4
4127.608	4127.613	FE I 357	121	14	10	8	2
4132.073	4132.067	FE I 43	404	107	63	40	15
4134.699	4134.685	FE I 357	129	15	10	7	1
4138.419				10	3	0	0
4143.423	4143.416	FE I 523	134	23	14	11	5
4143.886	4143.878	FE I 43	466	229	122	82	58
4154.497	4154.505	FE I 355	126	23	18	7	5
4162.955				13	12	7	3
4174.938	4174.933	FE I 19	103	15	2	0	0
4175.632	4175.643	FE I 354	110	13	3	6	5
4181.764	4181.764	FE I 354	148	39	11	12	6
4184.888				8	1	5	0
4197.056				16	5	3	1
4199.099	4199.105	FE I 522	183	53	25	19	4
4202.036	4202.040	FE I 42	326	192	108	69	39
4203.991	4204.004	FE I 355	123	10	6	4	0
4206.682	4206.702	FE I 3	122	19	13	14	9
4215.184				12	9	1	3
4216.188	4216.191	FE I 3	130	77	39	18	9
4219.372	4219.355	FE I 800	146	16	13	10	8
4226.742	4226.740	CA I 2	1476	65	27	12	6
4243.611				6	4	1	0
4245.273	4245.264	FE I 352	118	19	11	6	4
4246.236				12	6	5	2
4250.800	4250.797	FE I 42	400	103	54	29	12
4252.630				12	5	0	0
4254.347	4254.346	CR I 1	393	79	31	16	8
4261.144				12	6	0	0
4271.772	4271.774	FE I 42	756	321	181	115	61
4274.809	4274.806	CR I 1	196	52	18	10	3
4282.415	4282.412	FE I 71	146	43	23	13	7

TABLE II (*continued*)

Observed wavelength	Solar wavelength	Identification			Observed intensity			
		RMT No.	Int.		Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
4289.724	4289.729	CR I 1	230		57	22	12	2
4291.470	4291.472	FE I 41	84		38	20	13	6
4294.137	4294.142	FE I 41	217		151	77	47	16
4307.916	4307.912	FE I 42	723		374	222	110	78
4315.098	4315.098	FE I 71	153		30	15	10	7
4325.772	4325.775	FE I 42	793		222	133	80	49
4337.059	4337.055	FE I 41	120		35	27	12	12
4352.755	4352.743	FE I 71	142		20	15	7	8
4375.942	4375.944	FE I 2	152		165	76	35	19
4379.237	4379.238	V I 22	110		20	12	8	2
4383.563	4383.557	FE I 41	1008		538	342	258	148
4404.762	4404.761	FE I 41	898		455	256	140	87
4407.709	4407.706	FE I 68	146		3	1	0	0
4408.420	4408.425	FE I 68	130		3	0	2	5
4415.125	4415.135	FE I 41	417		279	125	76	38
4427.317	4427.317	FE I 2	147		142	67	25	21
4430.623	4430.622	FE I 68	115		13	10	5	5
4442.342	4442.349	FE I 68	171		25	18	9	9
4443.195	4443.201	FE I 350	95		15	15	12	4
4444.897					14	13	11	7
4447.732	4447.728	FE I 68	177		20	21	9	2
4458.471					5	3	2	4
4459.141	4459.138	FE I 68	190		35	20	10	5
4459.580					5	4	3	0
4461.670	4461.660	FE I 2	116		35	21	11	8
4466.560	4466.562	FE I 350	125		28	18	10	6
4476.037	4476.033	FE I 350	152		30	22	10	8
4482.194	4482.174	FE I 2	165		43	22	13	8
4489.749	4489.748	FE I 2	81		16	5	6	7
4494.575	4494.573	FE I 68	139		47	30	15	9
4528.628	4528.627	FE I 68	275		114	44	33	9
4530.285					7	3	0	0
4531.172	4531.158	FE I 39	106		9	6	9	4
4592.659	4592.659	FE I 39	95		16	10	5	4
4602.945	4602.949	FE I 39	97		16	8	8	2
5012.075	5012.075	FE I 16	154		69	36	20	14
5041.775	5041.763	FE I 36	158		13	11	7	5
5049.827	5049.827	FE I 114	135		22	4	6	5
5051.649	5051.642	FE I 16	111		37	12	18	8
5083.359	5083.345	FE I 16	95		15	10	3	0
5105.545	5105.545	CU I 2	82		20	16	11	4
5110.422	5110.435	FE I 1	126		69	41	23	20
5123.751	5123.730	FE I 16	101		14	11	5	2
5127.358	5127.368	FE I 16	85		19	13	8	4
5142.942	5142.936	FE I 16	111		16	8	4	2
5151.895	5151.917	FE I 16	100		14	8	2	0
5157.641					12	4	1	0
5165.082					10	4	0	0
5166.289	5166.284	FE I 1	115		39	25	8	8
5167.498	5167.508	FE I 37	935		197	142	47	29

TABLE II (continued)

Observed wavelength	Solar wavelength	Identification		Observed intensity			
		RMT No.	Int.	Head 0.0	Tail 1.0	Head 1.3	Tail 2.0
5168.915				11	7	0	0
5171.604	5171.610	FE I 36	160	44	30	12	12
5194.946	5194.949	FE I 36	126	29	24	8	12
5202.372	5202.348	FE I 66	155	10	9	2	0
5204.531	5204.513	CR I 7	212	16	9	4	2
5206.040	5206.044	CR I 7	216	15	11	8	4
5208.425	5208.432	CR I 7	247	20	12	1	3
5216.283	5216.283	FE I 36	108	22	16	8	8
5227.190	5227.192	FE I 114	277	126	60	35	16
5269.550	5269.550	FE I 15	478	379	175	158	55
5270.371				70	34	31	10
5328.051	5328.051	FE I 15	375	239	96	85	27
5328.541	5328.542	FE I 37	210	43	17	15	6
5341.025	5341.033	FE I 37	180	30	10	9	3
5371.501	5371.501	FE I 15	294	192	89	66	26
5397.132	5397.141	FE I 15	239	175	73	61	21
5405.788	5405.785	FE I 15	266	157	68	61	23
5429.706	5429.706	FE I 15	285	175	72	67	20
5434.526	5434.534	FE I 15	184	110	48	46	19
5446.930	5446.924	FE I 37	238	131	59	49	18
5455.617	5455.624	FE I 15	219	100	45	38	12
5476.923	5476.921	NI I 59	164	45	17	15	11
5497.506	5497.526	FE I 15	128	11	7	2	1
5501.467	5501.477	FE I 15	115	10	4	0	0
5506.791	5506.791	FE I 15	120	20	11	8	4
5889.980	5889.973	NA I 1	752	*	*	*	*
5895.949	5895.940	NA I 1	564	*	*	*	*

millimeters on the plates, from the central condensation. For brevity "head" is taken to be a displacement in the direction of the sun and "tail" in the antisolar direction.

Tabulated values of the intensity represent averages of the two independent reduction sequences weighted equally. Additional averages have been taken of duplications resulting from plate overlap.

As a consequence of the work to obtain this tabulation, an atlas of the comet spectrum is available upon request. The atlas consists of 56 graphs of the emission spectrum and observed spectrum from $\lambda\lambda 3200$ –6040 Å.

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