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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

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Spectrophotometric Standards for the 1962 Total Solar Eclipse

F.Q. ORRALL

OFFICE OF AEROSPACE RESEARCH

United States Air Force

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SPECTROPHOTOMETRIC STANDARDS FOR THE 1962 TOTAL SOLAR ECLIPSE

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SACRAMENTO PEAK OBSERVATORY PROJECT 7649

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Abstract

This report contains the information needed to make spectrophotometric measurements on the numerous "jumping-film" spectrograms obtained at the total solar eclipse of 4 and 5 February 1962 at Lae, New Guinea, by a joint expedition of the High Altitude Observatory, the National Bureau of Standards, and the Sacramento Peak Observatory (AFCRL). It includes a brief description of the instrument, a catalog describing each of the spectrograms, characteristic curves for the photographic emulsions used, and a procedure for reducing photometric measurements to absolute intensity.

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Spectrophotometric Standards for the 1962 Total Solar Eclipse

1. INTRODUCTION

At the total solar eclipse of 4 and 5 February 1962, at Lae, New Guinea, a joint expedition of the High Altitude Observatory, the National Bureau of Standards, and the Sacramento Peak Observatory (AFCRL) was successful in recording a very complete set of "jumping-film" chromospheric spectrograms – the most complete set yet obtained. The experiment failed in 1958 in the Cook Islands and in 1959 in the Canary Islands because of very heavy overcast at the time of the eclipse; but in 1962 the clouds opened just before totality making good observations possible.

More than 400 calibrated spectra were obtained in all, including observations at second and third contacts and during totality. One representative chromospheric region on the east limb has been measured in detail, and intensities as a function of height have been determined for 3,000 emission lines (Dunn et al., 1967). This is only a small fraction of the information concerning limb darkening, chromospheric structure, and prominences that is contained on these spectrograms. It is the purpose of this report to present the photometric standardization and other data that may facilitate and encourage further study of this important collection of eclipse spectrograms.

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Section 2 contains a brief description of the instrument; Section 3 describes the observations and includes a catalog of the individual spectrograms; and Section 4 describes the photometric standardization and contains the information needed for extracting further spectrophotometric data from the spectrograms.

2. INSTRUMENTATION

The instrument consisted of two spectrograph cameras fed by a common telescope and collimator. The mirror telescope, of 40-cm aperture, was fed by a coelostat; it formed a solar image of 54.2 mm in diameter in the primary focal plane – that is, the slit plane of the spectrograph. No slit was used, however, for the observations made at second and third contact. Instead, only a curved slot was used that admitted the entire chromospheric crescent from one limb at a time. During totality the slot was replaced by curved slits in order to obtain slit spectra of the corona and prominences.

After being collimated, the light from the primary image was divided into two beams. One beam fed a grating and a camera that recorded the spectrum from λ3100 to λ9100 at a linear dispersion of 10 Å/mm. Hereafter, we shall refer to this as the "IR spectrograph." The other beam fed a "UV spectrograph" that recorded the spectrum from λ3100 to λ7000 at 6 Å/mm. Light from the collimator was incident on the grating at a high angle, while the diffracted beam was nearly normal to the grating. This reduced the width of the sun's crescent by a factor of about 1/3 and thus considerably improved the spectral resolution of the slitless spectra. A wedge-type beam splitter between the collimator and the grating produced three images of each spectrum, successive images differing in intensity approximately in the ratio 1:20:400. Both gratings were used in the first order – sheets of Kodak Wratten filter just in front of the final focal plane eliminated higher orders. Each exposure, consisting of the three spectra, required a piece of film 60 by 15 cm. In order to feed the two spectrographs with such large amounts of film at a sufficiently rapid rate, each spectrograph camera had two camera backs so that one could be transporting fresh film into place while the other was recording. Each grating rocked back and forth to feed the two camera backs alternately. A vacuum system was required for each camera back in order to make the film conform to the highly curved focal surface.

A set of binary lamp banks that imposed a serial number on each frame for positive identification was imaged onto the end of each exposure. Also imaged onto each frame by means of a small calibration spectrograph was the spectrum of a tungsten lamp to serve as a secondary photometric standard. These frame numbers, the time of opening and closing of the shutters, the rocking of the gratings, and the transport of the films were recorded on a 100-channel recorder. The timing of the exposures and the operation of the spectrographs during the eclipse were programmed by electronic control.

Figure 1 shows the spectrographs as modified by Dunn for the 1962 eclipse. A more complete description of the instrument has been given by Dunn et al. (1967) and by Henze (1967). A description of the instrument as it was originally built for the 1958 and 1959 eclipses has been given by Low (1958).

3. OBSERVATIONS OBTAINED

The eclipse occurred on the morning of 5 February 1962 by local time; but the universal date was 4 February and the UT's of second and third contacts were $22^h50^m45\overset{s}{.}00$ and $22^h53^m27\overset{s}{.}38$, respectively. The observing program consisted of the following three parts:

1. Around second contact, numerous slitless spectra were obtained of the disappearing crescent of the east limb.
2. During totality, several slit spectra were made with varying exposure times of the corona and prominences, first above the east limb and then above the west limb.
3. Around third contact, numerous slitless spectra were obtained of the re-appearing crescent of the west limb.

The program was as follows: About 20 seconds prior to second contact, the shrinking solar crescent was guided onto a slot that admitted about 120° of the east limb and the spectrograph cameras were started. The UV spectrograph camera took spectra with an exposure duration of about 0.22 sec at a rate of 3 per sec, and the IR spectrograph camera took spectra with an exposure duration of about 0.52 sec at a rate of 1.5 per sec. The cameras ran at this rate for about 40 sec – that is, 20 sec into totality. A curved slit was then put in place to admit the light from the corona above the east limb and several spectrograms were taken of various durations. A similar slit, curved in the opposite direction, was positioned to admit light from the corona above the west limb and additional exposures were made. A slot similar to that used in second contact but curved for the west limb was put in place, and 30 sec before third contact the cameras were again run for about 50 sec at the same rates and exposure durations used at second contact.

When about half of the sun's disk was exposed, the primary photometric standards were obtained as follows: A straight slit was placed in the slit plane of the spectrograph and covered with a step-attenuator. The exposed portion of the sun's disk was imaged onto this slit and its position on the slit noted. The spectrograph cameras were again started and run for about 20 sec at the same rates and exposure

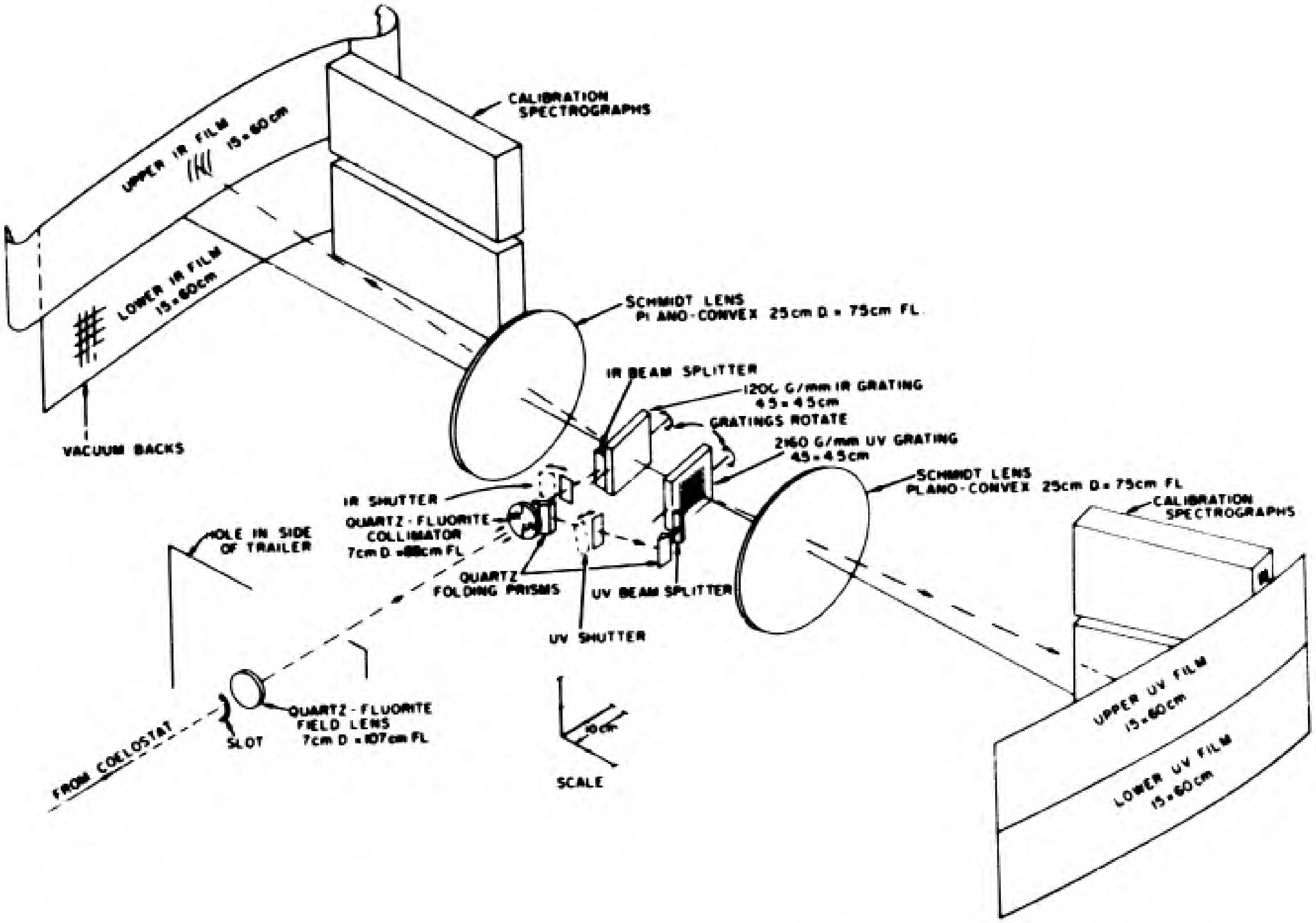

Figure 1. A Schematic Drawing of the Spectrographs as Used at the 1962 Eclipse

durations as those used at second and third contacts. Clouds moved in front of the sun during these observations, but enough spectra were obtained free of clouds to serve as good photometric standards.

The observations, including the photometric standard spectra described above, were contained on four rolls of film, one from each of the four camera backs. After these rolls of film were developed they were cut into 60-cm lengths, each length containing one exposure – that is, one set of three images of each spectrum with the binary identification number and secondary photometric standards imposed on one end. Each length was mounted separately between pieces of flat plate glass. Hereafter, each exposure or length of film will be referred to in general as a "plate." Because each spectrograph had two camera backs, the odd-numbered plates were obtained on a different roll of film and with a different camera back than the even-numbered plates.

Tables 1 and 2 are catalogs of the ultraviolet and the infrared spectrograms, respectively. The first column gives the plate number and the second gives the UT of the middle of the exposure. The third gives t , the duration of the exposure for that spectrogram. Columns 4 and 5 contain factors to be used in the photometric calibration and will be discussed in Section 4. The numbers in the final column refer to descriptive notes at the bottom of the table. Plates UV 8 through UV 118 and IR 6 through IR 60 comprise the second contact program at the east limb; plates UV 136 through UV 290 and IR 74 through IR 151 comprise the third contact program at the west limb. Plates UV 123 through UV 131 and IR 63 through IR 71 comprise the totality program using the curved slit. These slit spectra are generally under exposed. Plate UV 4, UV 5, UV 6 and IR 4 are of a special interest. They were obtained before second contact with the curved slit (used during the totality program) cutting across the solar crescent. Thus, they contain well-exposed slit spectra of the chromosphere. The photometric standards obtained with the sun's image illuminating a straight slit covered with a step-attenuator are contained on plates UV 294 through UV 352 and IR 154 through IR 179.

The UT of each exposure and the exposure durations given in columns 2 and 3 were obtained from the 100-channel recorder. The length of each exposure and the relative time between exposures is known within an accuracy of ±0.001 sec. The actual UT is known probably to an accuracy of ±0.1 sec (certainly to ±0.2 sec).

4. PHOTOMETRIC STANDARDIZATION

The primary photometric calibration is based on the spectrograms taken after the eclipse with the sun imaged onto a slit (covered with a step-attenuator) placed in the primary focal plane, as described in Section 3. Thus, the sun's disk is the primary standard source. Since the brightness of the sun's disk is known as a function of wavelength and position and since the optical transmission of each step

Table 1. The Ultraviolet Spectrograms

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Corr. Factor	Notes
1					(1)
2					(1)
3					(1)
4	$22^h50^m25^s.268$	0.222			(2)
5	25.614	0.243			(3)
6	25.958	0.226			(4)
7	26.299	0.224			(5)
8	26.637	0.224			(6)
9	26.973	0.224			
10	27.309	0.224			
11	27.646	0.222			
12	27.983	0.225			
13	28.316	0.223			
14	28.654	0.222			
15	28.991	0.222			
16	29.328	0.222			
17	29.663	0.223			
18	30.001	0.224			
19	30.337	0.222			
20	30.674	0.222	1.003	1.003	
21	31.012	0.223	0.997	1.093	
22	31.346	0.224	0.995	0.995	
23	31.683	0.223	0.997	1.093	
24	32.020	0.223	0.999	0.999	
25	32.355	0.223	0.997	1.093	
26	32.693	0.224	0.995	0.995	
27	33.030	0.223	0.997	1.093	
28	33.368	0.222	1.003	1.003	
29	33.703	0.223	0.997	1.093	
30	34.039	0.222	1.003	1.003	
31	34.375	0.221	1.006	1.103	
32	34.713	0.222	1.003	1.003	
33	35.048	0.223	0.997	1.093	
34	35.385	0.221	1.008	1.008	
35	35.720	0.223	0.997	1.093	
36	36.057	0.222	1.003	1.003	
37	36.392	0.223	0.997	1.093	
38	36.728	0.223	0.999	0.999	
39	37.063	0.223	0.997	1.093	
40	37.400	0.221	1.008	1.008	
41	37.736	0.223	0.997	1.093	
42	38.070	0.222	1.003	1.003	
43	38.404	0.223	0.997	1.093	
44	38.741	0.222	1.003	1.003	
45	39.075	0.222	1.001	1.098	
46	39.410	0.223	0.999	0.999	
47	39.748	0.222	1.001	1.098	
48	40.081	0.222	1.003	1.003	
49	40.419	0.221	1.006	1.103	
50	40.755	0.221	1.008	1.008	

Table 1. The Ultraviolet Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Corr. Factor	Notes
51	$22^h50^m41\overset{s}{.}090$	0.221	1.006	1.103	
52	41.426	0.222	1.003	1.003	
53	41.761	0.223	0.997	1.093	
54	42.096	0.221	1.008	1.008	
55	42.431	0.222	1.001	1.098	
56	42.767	0.222	1.003	1.003	
57	43.102	0.223	0.997	1.093	
58	43.437	0.223	0.999	0.999	
59	43.775	0.223	0.997	1.093	
60	44.112	0.223	0.999	0.999	
61	44.446	0.222	1.001	1.098	
62	44.783	0.221	1.008	1.008	
63	45.119	0.221	1.006	1.103	
64	45.454	0.223	0.999	0.999	
65	45.792	0.222	1.001	1.098	
66	46.128	0.222	1.003	1.003	
67	46.463	0.222	1.001	1.098	
68	46.801	0.223	0.999	0.999	
69	47.138	0.223	0.997	1.093	
70	47.473	0.222	1.003	1.003	
71	47.811	0.223	0.997	1.093	
72	48.146	0.222	1.003	1.003	
73	48.482	0.222	1.001	1.098	
74	48.819	0.222	1.003	1.003	
75	49.155	0.222	1.001	1.098	
76	49.492	0.221	1.008	1.008	
77	49.828	0.223	0.997	1.093	
78	50.165	0.223	0.999	0.999	
79	50.500	0.222	1.001	1.098	
80	50.836	0.222	1.003	1.003	
81	51.173	0.223	0.997	1.093	
82	51.509	0.223	0.999	0.999	
83	51.843	0.222	1.001	1.098	
84	52.181	0.224	0.995	0.995	
85	52.517	0.223	0.997	1.093	
86	52.853	0.221	1.008	1.008	
87	53.189	0.223	0.997	1.093	
88	53.525	0.222	1.003	1.003	
89	53.860	0.223	0.997	1.093	
90	54.196	0.222	1.003	1.003	
91	54.533	0.221	1.006	1.103	
92	54.869	0.222	1.003	1.003	
93	55.205	0.221	1.006	1.103	
94	55.541	0.223	0.999	0.999	
95	55.876	0.222	1.001	1.098	
96	56.213	0.221	1.008	1.008	
97	56.548	0.223	0.997	1.093	
98	56.884	0.223	0.999	0.999	
99	57.220	0.220	1.011	1.108	
100	57.558	0.222	1.003	1.003	

Table 1. The Ultraviolet Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Corr. Factor	Notes
101	$22^h50^m57\overset{s}{.}841$	0.223	0.997	1.093	
102	58.228	0.223	0.999	0.999	
103	58.564	0.222	1.001	1.098	
104	58.902	0.221	1.008	1.008	
105	59.237	0.222	1.001	1.098	
106	59.574	0.220	1.013	1.013	
107	59.908	0.222	1.001	1.098	
108	$22^h51^m00\overset{s}{.}246$	0.222	1.003	1.003	
109	00.582	0.223	0.997	1.093	
110	00.918	0.222	1.003	1.003	
111	01.254	0.223	0.997	1.093	
112	01.591	0.223	0.999	0.999	
113	01.927	0.223	0.997	1.093	
114	02.263	0.223	0.999	0.999	
115	02.599	0.222	1.001	1.098	
116	02.937	0.222	1.003	1.003	
117	03.271	0.223	0.997	1.093	
118	03.609	0.221	1.008	1.008	(6)
119	03.943	0.220	1.011	1.108	(7)
120	04.279	0.221	1.008	1.008	(7)
121	04.616	0.223	0.997	1.093	(7)
122	04.940	0.221	1.008	1.008	(7)
123	10.146	9.978	0.0222	0.0243	(8)
124	19.484	8.492	0.0263	0.0263	(8)
125	25.212	2.742	0.810	0.0888	(8)
126	30.303	7.220	0.0309	0.0309	(8)
127	44.731	41.465	0.00535	0.00586	(8)
128	$22^h52^m19\overset{s}{.}850$	8.569	0.0260	0.0260	(9)
129	25.578	2.682	0.0880	0.0964	(9)
130	30.268	7.562	0.0295	0.0295	(9)
131	44.393	20.106	0.0110	0.0121	(9)
132	54.678	0.222	1.005	1.005	(7)
133	55.003	0.226	0.982	1.076	(7)
134	55.360	0.242	0.922	0.922	(7)
135	55.699	0.220	1.011	1.108	(7)
136	56.038	0.223	0.999	0.999	(10)
137	56.372	0.220	1.011	1.108	
138	56.708	0.221	1.008	1.008	
139	57.044	0.218	1.020	1.118	
140	57.381	0.223	0.999	0.999	
141	57.715	0.222	1.001	1.098	
142	58.051	0.222	1.003	1.003	
143	58.385	0.219	1.015	1.113	
144	58.722	0.222	1.003	1.003	
145	59.060	0.219	1.015	1.113	
146	59.394	0.222	1.003	1.003	
147	59.732	0.219	1.015	1.113	
148	$22^h53^m00\overset{s}{.}068$	0.219	1.017	1.017	
149	00.402	0.219	1.015	1.113	
150	00.738	0.222	1.003	1.003	

Table 1. The Ultraviolet Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Corr. Factor	Notes
151	$22^h53^m00\overset{s}{.}175$	0.217	1.025	1.123	
152	01.412	0.221	1.008	1.008	
153	01.746	0.218	1.020	1.118	
154	02.081	0.220	1.013	1.013	
155	02.417	0.219	1.015	1.113	
156	02.753	0.222	1.003	1.003	
157	03.087	0.219	1.015	1.113	
158	03.423	0.221	1.008	1.008	
159	03.760	0.219	1.015	1.113	
160	04.097	0.223	0.999	0.999	
161	04.433	0.220	1.011	1.108	
162	04.768	0.223	0.999	0.999	
163	05.105	0.218	1.020	1.118	
164	05.441	0.222	1.003	1.003	
165	05.774	0.220	1.011	1.108	
166	06.110	0.222	1.003	1.003	
167	06.445	0.218	1.020	1.118	
168	06.782	0.222	1.003	1.003	
169	07.114	0.221	1.006	1.103	
170	07.452	0.222	1.003	1.003	
171	07.789	0.218	1.020	1.118	
172	08.124	0.222	1.003	1.003	
173	08.459	0.217	1.025	1.123	
174	08.797	0.219	1.017	1.017	
175	09.131	0.219	1.015	1.113	
176	09.467	0.221	1.008	1.008	
177	09.802	0.220	1.011	1.108	
178	10.138	0.221	1.008	1.008	
179	10.475	0.217	1.025	1.123	
180	10.808	0.222	1.003	1.003	
181	11.144	0.219	1.015	1.113	
182	11.478	0.221	1.008	1.008	
183	11.814	0.218	1.020	1.118	
184	12.151	0.220	1.013	1.013	
185	12.486	0.219	1.015	1.113	
186	12.820	0.221	1.008	1.008	
187	13.155	0.216	1.029	1.128	
188	13.493	0.221	1.008	1.008	
189	13.826	0.216	1.029	1.128	
190	14.160	0.219	1.017	1.017	
191	14.496	0.217	1.025	1.123	
192	14.833	0.219	1.017	1.017	
193	15.168	0.218	1.020	1.118	
194	15.504	0.221	1.008	1.008	
195	15.839	0.216	1.029	1.128	
196	16.175	0.217	1.027	1.027	
197	16.509	0.218	1.020	1.118	
198	16.845	0.219	1.017	1.017	
199	17.181	0.217	1.025	1.123	
200	17.517	0.219	1.017	1.017	

Table 1. The Ultraviolet Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Corr. Factor	Notes
201	$22^h53^m17^s.851$	0.218	1.020	1.118	
202	18.186	0.221	1.008	1.008	
203	18.522	0.216	1.029	1.128	
204	18.859	0.219	1.017	1.017	
205	19.193	0.218	1.020	1.118	
206	19.528	0.219	1.017	1.017	
207	19.864	0.218	1.020	1.118	
208	20.200	0.218	1.022	1.022	
209	20.533	0.218	1.020	1.118	
210	20.870	0.220	1.013	1.013	
211	21.204	0.217	1.025	1.123	
212	21.541	0.221	1.008	1.008	
213	21.874	0.217	1.025	1.123	
214	22.211	0.220	1.013	1.013	
215	22.546	0.218	1.020	1.118	
216	22.883	0.219	1.017	1.017	
217	23.217	0.216	1.029	1.128	
218	23.552	0.220	1.013	1.013	
219	23.888	0.218	1.020	1.118	
220	24.223	0.219	1.017	1.017	
221	24.558	0.218	1.020	1.118	
222	24.892	0.221	1.008	1.008	
223	25.227	0.216	1.029	1.128	
224	25.564	0.220	1.013	1.013	
225	25.899	0.218	1.020	1.118	
226	26.235	0.221	1.008	1.008	
227	26.570	0.218	1.020	1.118	
228	26.906	0.220	1.013	1.013	
229	27.241	0.218	1.020	1.118	
230	27.575	0.221	1.008	1.008	
231	27.912	0.217	1.025	1.123	
232	28.247	0.222	1.003	1.003	
233	28.581	0.219	1.015	1.113	
234	28.916	0.221	1.008	1.008	
235	29.252	0.218	1.020	1.118	
236	29.587	0.220	1.013	1.013	
237	29.923	0.218	1.020	1.118	
238	30.259	0.221	1.008	1.008	
239	30.594	0.217	1.025	1.123	
240	30.930	0.222	1.003	1.003	
241	31.263	0.215	1.034	1.133	
242	31.600	0.221	1.008	1.008	
243	31.936	0.218	1.020	1.118	
244	32.272	0.219	1.017	1.017	
245	32.607	0.219	1.015	1.113	
246	32.941	0.221	1.008	1.008	
247	33.276	0.219	1.015	1.113	
248	33.612	0.222	1.003	1.003	
249	33.94[illegible]	0.222	1.001	1.097	
250	34.28[illegible]	0.220	1.013	1.013	

Table 1. The Ultraviolet Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Corr. Factor	Notes
251	$22^{h}53^{m}34^{s}.619$	0.217	1.025	1.123	
252	34.956	0.222	1.003	1.003	
253	35.292	0.218	1.020	1.118	
254	35.626	0.222	1.003	1.003	
255	35.963	0.218	1.020	1.118	
256	36.299	0.222	1.003	1.003	
257	36.632	0.218	1.020	1.118	
258	36.970	0.219	1.017	1.017	
259	37.304	0.219	1.015	1.113	
260	37.639	0.221	1.008	1.008	
261	37.974	0.218	1.020	1.118	
262	38.310	0.221	1.008	1.008	
263	38.644	0.216	1.029	1.128	
264	38.980	0.222	1.003	1.003	
265	39.315	0.219	1.015	1.113	
266	39.650	0.222	1.003	1.003	
267	39.986	0.218	1.020	1.118	
268	40.322	0.224	0.995	0.995	
269	40.657	0.218	1.020	1.118	
270	40.992	0.223	0.999	0.999	
271	41.330	0.221	1.006	1.103	
272	41.669	0.224	0.995	0.995	
273	42.004	0.221	1.006	1.103	
274	42.345	0.223	0.999	0.999	
275	42.681	0.220	1.011	1.108	
276	43.021	0.221	1.008	1.008	
277	43.360	0.221	1.006	1.103	
278	43.698	0.223	0.999	0.999	
279	44.035	0.220	1.011	1.108	
280	44.375	0.224	0.995	0.995	
281	44.712	0.224	0.993	1.088	
282	45.051	0.221	1.006	1.006	
283	45.388	0.222	1.003	1.099	
284	45.726	0.223	0.997	0.997	
285	46.061	0.221	1.006	1.103	
286	46.398	0.221	1.008	1.008	
287	46.734	0.219	1.015	1.112	
288	47.072	0.222	1.003	1.003	
289					(10)
290					(10)(11)
291					(12)(13)
292					(11)(13)
293					(12)(13)
294					(13)
295		0.224			(13)
296		0.222			
297		0.222			
298		0.223			
299		0.223			
300		0.223			

Table 1. The Ultraviolet Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Corr. Factor	Notes
301		0.221			
302		0.222			
303		0.221			
304		0.222			
305		0.223			
306		0.224			
307		0.224			
308		0.223			
309		0.221			
310		0.223			
311		0.223			
312		0.222			
313		0.220			
314		0.223			
315		0.222			
316		0.222			
317		0.220			
318		0.221			
319		0.223			
320		0.223			
321		0.220			
322		0.222			
323		0.219			
324		0.223			
325		0.219			
326		0.221			
327		0.220			
328		0.220			
329		0.221			
330		0.223			
331		0.223			
332		0.219			
333		0.219			
334		0.222			
335		0.220			
336		0.219			
337		0.220			
338		0.219			
339		0.222			
340		0.223			
341		0.222			
342		0.223			
343		0.222			
344		0.223			
345		0.219			
346		0.222			
347		0.223			
348		0.219			
349		0.221			
350		0.224			

Table 1. The Ultraviolet Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Corr. Factor	Notes
351		0.223			(13)
352		0.222			(1)
353		0.219			(13)
354		0.221			(1)
355		0.221			

Notes: The Ultraviolet Spectrograms

(1) Plate discarded or missing.
(2) Slit in; mostly blank; only 5 in. of short wavelength end are exposed.
(3) Slit in; well exposed except for fogging at red end.
(4) Slit in; well exposed.
(5) Only partly exposed, slit in motion.
(6) Second contact slot in for plates 8 through 118.
(7) Blank or thoroughly underexposed except for end wedge and plate number.
(8) Second contact slit in place.
(9) Third contact slit in place.
(10) Third contact slot in for plates 136 through 290.
(11) Plates 290 and 292 are superposed.
(12) Plates 291 and 293 are superposed.
(13) Straight slit covered with step-attenuator illuminated with sun's image on slit for plates 291 through 355.
(14) End wedge and part of spectrum missing.

Table 2. The Infrared Spectrograms

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Notes
1				(1)
2				(1)
3				(1)
4	$22^h50^m25\overset{s}{.}937$	0.524	0.997	(2)
5	26.606	0.515	0.990	(3)
6	27.282	0.517	1.011	(4)
7	27.956	0.512	0.996	
8	28.631	0.519	1.007	
9	29.301	0.511	0.998	
10	29.978	0.520	1.005	
11	30.649	0.512	0.996	
12	31.324	0.521	1.003	
13	31.993	0.515	0.990	
14	32.670	0.520	1.005	
15	33.342	0.515	0.990	

Table 2. The Infrared Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Notes
16	$22^h50^m34^s.018$	0.520	1.005	
17	34.686	0.515	0.990	
18	35.360	0.520	1.005	
19	36.031	0.514	0.992	
20	36.707	0.518	1.009	
21	37.376	0.509	1.002	
22	38.047	0.517	1.011	
23	38.714	0.513	0.994	
24	39.387	0.518	1.009	
25	40.057	0.512	0.996	
26	40.730	0.522	1.001	
27	41.401	0.513	0.994	
28	42.075	0.515	1.015	
29	42.741	0.509	1.002	
30	43.415	0.517	1.011	
31	44.085	0.512	0.996	
32	44.761	0.515	1.015	
33	45.429	0.513	0.994	
34	46.104	0.517	1.011	
35	46.776	0.511	0.998	
36	47.443	0.516	1.013	
37	48.120	0.511	0.998	
38	48.796	0.516	1.013	
39	49.466	0.511	0.998	
40	50.141	0.517	1.011	
41	50.811	0.512	0.996	
42	51.486	0.518	1.009	
43	52.156	0.511	0.998	
44	52.830	0.516	1.013	
45	53.501	0.510	1.000	
46	54.174	0.515	1.015	
47	54.844	0.512	0.996	
48	55.518	0.516	1.013	
49	56.186	0.514	0.992	
50	56.860	0.518	1.009	
51	57.531	0.509	1.002	
52	58.204	0.518	1.009	
53	58.877	0.511	0.998	
54	59.551	0.515	1.015	
55	$22^h51^m00^s.220$	0.511	0.998	
56	00.894	0.517	1.011	
57	01.564	0.511	0.998	
58	02.241	0.517	1.011	
59	02.910	0.510	1.000	
60	03.586	0.519	1.007	(4)
61	04.255	0.511	0.998	(5)
62	04.916	0.487	1.074	(6)
63	10.241	9.862	0.0517	(7)
64	19.581	8.510	0.0614	(7)
65	25.308	2.642	0.193	(7)

Table 2. The Infrared Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Notes
66	$22^h51^m30^s.380$	7.179	0.0728	(7)
67	54.822	41.417	0.0123	(7)
68	$22^h52^m19^s.933$	8.498	0.0615	(8)
69	25.652	2.616	0.195	(8)
70	30.698	7.145	0.0732	(8)
71	44.438	20.014	0.0255	(8)
72	54.812	0.512	1.021	(5)
73	55.535	0.506	1.008	(5)
74	56.227	0.520	1.005	(9)
75	56.898	0.507	1.006	
76	57.571	0.521	1.003	
77	58.242	0.505	1.010	
78	58.916	0.518	1.009	
79	59.585	0.507	1.006	
80	$22^h53^m00^s.258$	0.520	1.005	
81	00.930	0.504	1.012	
82	01.604	0.517	1.011	
83	02.180	0.508	1.004	
84	02.945	0.518	1.009	
85	03.615	0.505	1.010	
86	04.287	0.520	1.005	
87	04.959	0.506	1.008	
88	05.630	0.518	1.009	
89	06.300	0.504	1.012	
90	06.972	0.517	1.011	
91	07.644	0.504	1.012	
92	08.316	0.515	1.015	
93	08.984	0.507	1.006	
94	09.658	0.516	1.013	
95	10.328	0.501	1.018	
96	10.998	0.518	1.009	
97	11.669	0.505	1.010	
98	12.342	0.516	1.013	
99	13.012	0.506	1.008	
100	13.682	0.521	1.003	
101	14.352	0.505	1.010	
102	15.024	0.518	1.009	
103	15.691	0.506	1.008	
104	16.368	0.517	1.011	
105	17.037	0.505	1.010	
106	17.707	0.517	1.011	
107	18.379	0.504	1.012	
108	19.050	0.520	1.005	
109	19.718	0.504	1.012	
110	20.391	0.517	1.011	
111	21.059	0.504	1.012	
112	21.730	0.517	1.011	
113	22.400	0.504	1.012	
114	23.073	0.517	1.011	
115	23.742	0.503	1.014	

Table 2. The Infrared Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ/t	Notes
116	$22^{h}53^{m}24^{s}.414$	0.518	1.009	
117	25.083	0.503	1.014	
118	25.756	0.518	1.009	
119	26.427	0.502	1.016	
120	27.097	0.517	1.011	
121	27.766	0.504	1.012	
122	28.437	0.517	1.011	
123	29.107	0.506	1.008	
124	29.778	0.518	1.009	
125	30.449	0.505	1.010	
126	31.121	0.520	1.005	
127	31.790	0.503	1.014	
128	32.459	0.514	1.017	
129	33.134	0.505	1.010	
130	33.805	0.519	1.007	
131	34.475	0.503	1.014	
132	35.146	0.519	1.007	
133	35.816	0.505	1.010	
134	36.489	0.514	1.017	
135	37.161	0.502	1.016	
136	37.831	0.516	1.013	
137	38.501	0.502	1.016	
138	39.171	0.518	1.009	
139	39.841	0.505	1.010	
140	40.513	0.516	1.013	
141	41.185	0.506	1.008	
142	41.860	0.521	1.003	
143	42.537	0.509	1.002	
144	43.216	0.524	0.997	
145	43.889	0.509	1.002	
146	44.568	0.522	1.001	(9)
147	45.241	0.509	1.002	(9)(10)
148	45.918	0.518	1.009	(9)
149	46.588	0.506	1.008	(9)(10)
150				(9)(11)
151				(9)(12)
152				(11)
153				(13)(12)
154		0.557		(13)
155		0.509		
156		0.523		
157		0.510		
158		0.522		
159		0.508		
160		0.524		
161		0.508		
162		0.522		
163		0.512		
164		0.520		
165		0.508		

Table 2. The Infrared Spectrograms (Cont)

Plate No.	UT Middle of Exposure 4 Feb 1962	t	τ /t	Notes
166		0.525		
167		0.509		
168		0.521		
169		0.507		
170		0.521		
171		0.508		
172		0.520		
173		0.508		
174		0.522		
175		0.504		
176		0.520		
177		0.508		
178		0.517		
179		0.507		(13)
180		0.524		(1)
181		0.509		(13)
182		0.523		(1)

Notes: The Infrared Spectrograms

(1) Plate discarded or missing.
(2) Slit in, 6 in. at red end usable.
(3) Second contact slot in, part of plate missing.
(4) Second contact slot in for plates 6 through 60.
(5) Blank or thorougly underexposed except for end wedge and plate number.
(6) Blank except for plate number
(7) Second contact slit in.
(8) Third contact slit in.
(9) Third contact slot in for plates 74 through 151.
(10) Plates 147 and 149 are superposed.
(11) Plates 150 and 152 are superposed.
(12) Overexposed or fogged.
(13) Straight slit covered with step-attenuator illuminated with sun's image on slit for plates 153 through 181.

4.1 The Step-Attenuator

The step-attenuator consisted of a strip of glass upon which ten uniform, discrete, metallic steps of graded transparency had been deposited by evaporation. Since the step-attenuator was long (26 mm) compared with the diameter of the sun's image (54.2 mm), some correction for limb darkening was necessary. Table 3 gives μ_k, the value of $\mu = \cos\theta$ associated with each step of the attenuator k. The individual steps, k, are identified by letters from A to J, A being the most transparent and J the most opaque. The width of the slit varied somewhat along its length, but the width in microns at each step w_k is also given in Table 3. These values of μ_k and w_k are based on measurements made at the eclipse site. by Dunn.

Table 3. Slit Width and Position on the Disk for the Various Steps of the Attenuator

Step	w_k (microns)	μ_k
A	71.8	0.674
B	71.0	0.713
C	70.3	0.730
D	69.6	0.748
E	69.0	0.763
F	68.4	0.763
G	67.5	0.748
H	67.0	0.730
I	66.4	0.693
J	65.6	0.654

The transmission of each step of the wedge as a function of wavelength $T_k(\lambda)$ was measured photographically at the eclipse site, and photoelectrically after the eclipse using the 13-m spectrograph at Sacramento Peak Observatory. The photographic measurements were made by illuminating the calibrating slit uniformly with a tungsten lamp, care being taken to illuminate the apertures as they would be illuminated during the eclipse. Spectrograms were obtained first with the step-attenuator over the slit and then with it removed; $T_k(\lambda)$ was obtained by comparing the two on the microphotometer. (The spectrograms were calibrated by using rotating sectors in front of the slit.) Slightly different values of $T_k(\lambda)$ were obtained with the UV and IR spectrographs, probably because of scattered light. The photoelectric measurements show the same variation of T with λ and confirm that light was scattered from the brightest to the faintest steps. We have therefore used the effective values of the transmission which differ slightly with the two spectrographs as shown in Figure 2.

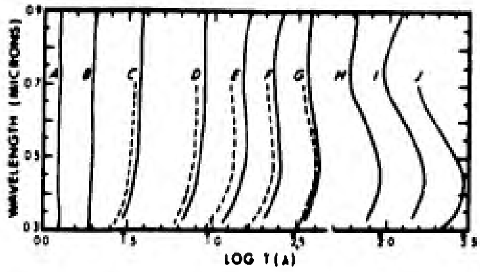

Figure 2. The Effective Transmission T(λ) of Each Step of the Step-Attenuator as a Function of Wavelength. Where measurements made in the UV and IR differ, the UV values are shown with dashed lines

1.2 The Photographic Characteristic Curves

The photographic emulsions used were Tri-X in the UV spectrograph and HIR in the IR spectrograph – both made by the Eastman Kodak Company. The four eclipse films were shipped under refrigeration to Rochester, New York, where they were developed by the Eastman Kodak Company using special equipment that insured nearly identical processing for the entire length of the films. We have assumed that the photometric properties of these films were uniform over their entire length; that is, we assume that at a given wavelength the same characteristic curve is valid for all of the IR spectrograms on HIR film. That this assumption is valid is clearly shown by Dunn et al. (1967) who find no significant difference between intensities measured on the odd and even-numbered plates even though they are recorded on different rolls of film (from the same emulsion batch).

The characteristic curves were determined as follows: Microphotometer tracings were made across the step-attenuated standard spectrograms at right angles to the direction of dispersion at a number of wavelengths (at 15 wavelengths between λ3261 and λ6690 on the UV spectrograms and at 36 wavelengths between λ 3481 and λ9038 on the IR spectrograms). At each of these wavelengths a characteristic curve was determined by plotting the photographic density (as derived from the microphotometer measurements) of the image of each step k against the log of the transmission log T_k. The values of log T_k used were those given in Figure 2 corrected for limb darkening and nonuniform slit width is given in Table 3.

Characteristic curves are usually expressed in diffuse density, whereas the microphotometer records a deflection that is some function of a specular density. It was thus necessary to provide some standard to calibrate the microphotometer. For this purpose, a graduated step tablet or standard step wedge was mounted on the microphotometer plate holder between pieces of glass of the same type used to mount the spectrograms. The diffuse density of the steps of this wedge are given in Table 4. By tracing this standard wedge one obtains a calibration of microphotometer deflection in terms of diffuse density. We found that consistent measures of diffuse density could be made in this way independent of emulsion type.

Table 4. Diffuse Densities of the Steps of the Standard Wedge Used to Calibrate the Microphotometer

Step No.	Density	Step No.	Density	Step No.	Density
0	0.10	7	1.46	14	2.75
1	0.30	8	1.71	15	2.92
2	0.50	9	1.93	16	3.07
3	0.74	10	2.12	17	3.22
4	0.90	11	2.29	18	3.41
5	1.09	12	2.44	19	3.58
6	1.26	13	2.60	20	3.76

The measured characteristic curves for the Tri-X film used in the UV spectrograph are shown in Figure 3 for various wavelengths and similar curves for the HIR film used in the IR spectrc ι aph are shown in Figures 4a through 4d. The curves have been displaced in log I so that their toes coincide. Thus, the zero point of the log I scale is arbitrary on all these curves. The large number of curves needed for the HIR film is a consequence of the different sensitizings needed to cover the large wavelength range.

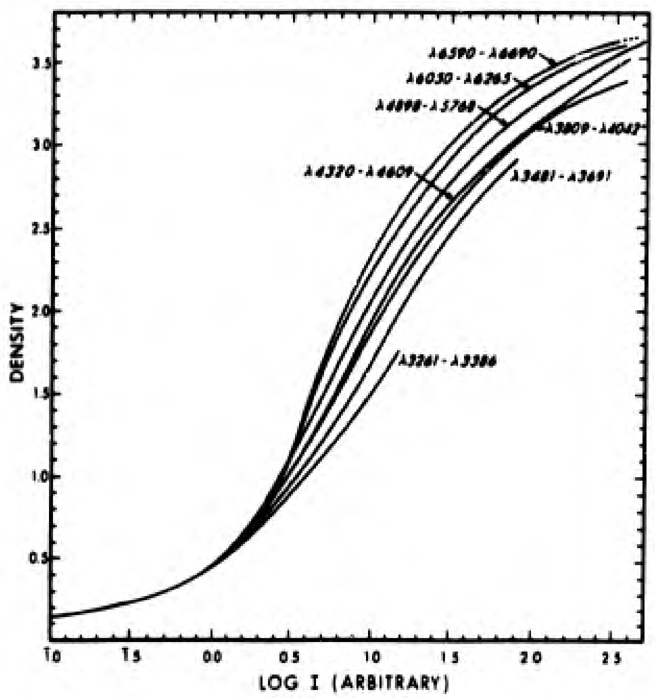

Figure 3. Characteristic Curves for the Eastman-Kodak Tri-X Film Used in the UV Spectrograph

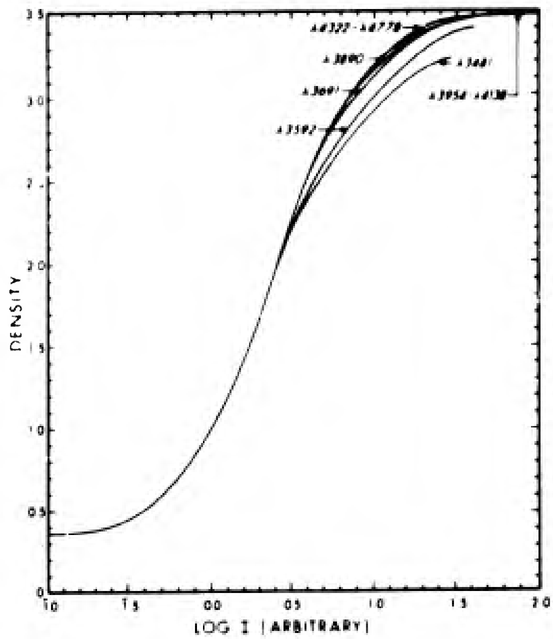

Figure 4a. Characteristic Curves for the Eastman-Kodak HIR Film Used in the IR Spectrograph in the Spectral Range λ3481 through λ4778

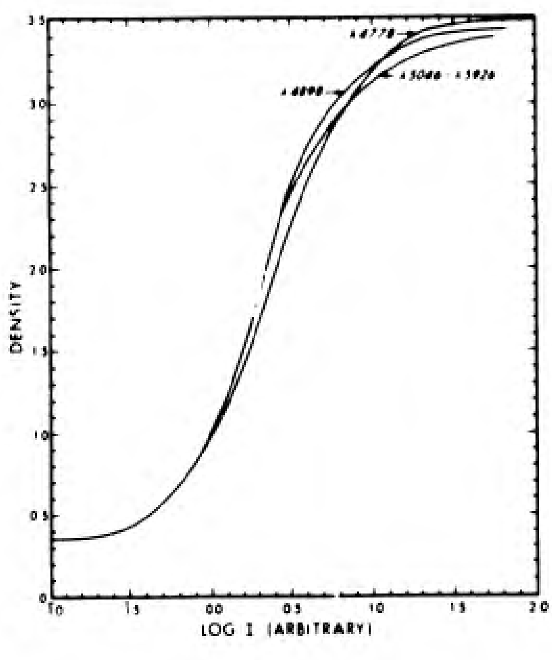

Figure 4b. Characteristic Curves for the Eastman-Kodak HIR Film Used in the IR Spectrograph in the Spectral Range λ4778 Through λ5926

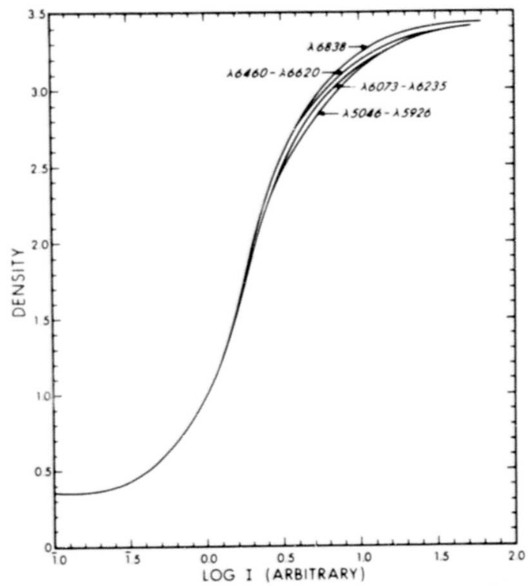

Figure 4c. Characteristic Curves for the Eastman-Kodak HIR Film Used in the IR Spectrograph in the Spectral Range λ5046 Through λ6838

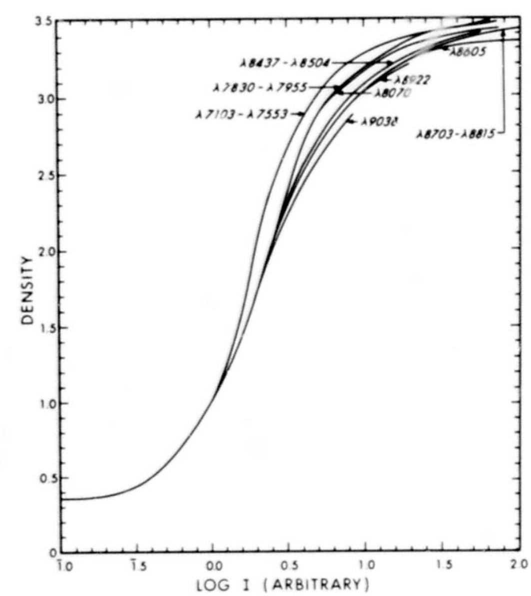

Figure 4d. Characteristic Curves for the Eastman-Kodak HIR Film Used in the IR Spectrograph in the Spectral Range λ7103 Through λ9038

4.3 The Absolute Calibration

The absolute calibration is simply the assignment of a true zero-point (which will vary with the wavelength) to the photographic characteristic curves given in Figures 3 and 4. To determine this zero point at a given wavelength, it is only necessary to know the photographic density of the spectrum of the solar disk observed at this wavelength through one of the steps of the step-attenuator and the effective intensity that produced this density. This effective intensity for step B (for example) at wavelength λ is

$$I_B(\lambda) = I(\lambda, 1) \left[I(\lambda, \mu_B)/I(\lambda, 1) \right] T_B(\lambda) W_B \quad . \tag{1}$$

Here $I(\lambda, 1)$ is the intensity at the center of the sun's disk (that is, at $\mu = 1$) measured at λ in the continuum between Fraunhofer lines. The ratio $[I(\lambda, \mu_B)/I(\lambda, 1)]$ is a correction for limb darkening necessary because step B was illuminated by light from a position on the disk defined by $\mu_B = 0.713$ as given in Table 3 rather than $\mu = 1$. The transmission of step B at this wavelength $T_B(\lambda)$ is given in Figure 2. The quantity W_B is the width of the calibrating slit at step B projected back onto the sun. The actual slit width w_k is given in Table 3 in microns. To find the width projected onto the sun this must be multiplied by the ratio of the sun's diameter to the diameter of its image in the primary focal plane. This ratio is $(13.92 \times 10^6 \text{ cm})/(5.42 \text{ cm}) = 2.5 \times 10^{10}$ and, with an additional factor of 10^{-4} to convert microns to centimeters, we find

$$W_k = 2.57 \times 10^6 \; w_k \quad , \tag{2}$$

the width of the slit in centimeters on the sun. We used for $I(\lambda, 1)$ the published values given in Figure 5. Where they disagreed we arbitrarily used the dashed curve — a mean between discordant measurements. More recent observations have since been published or are in press (see the recent summary by Michard, 1967); when these observations have been assessed, a slight correction can easily be made to the results of this paper. We have used for the small correction for limb darkening the results of Pierce and Waddell (1961).

A few difficulties complicated this procedure. First, the standards used in the above calibration were put on in haste because of approaching clouds, and there was no time to check the illumination of the apertures by the coelostat as had been done just prior to the eclipse. After the standards were taken it was found that one corner of the UV grating was not illuminated, whereas it had been during the eclipse. The fraction of the grating in shadow was carefully recorded by Dunn and based on his measures we have reduced the calculated photometric zero point for the UV

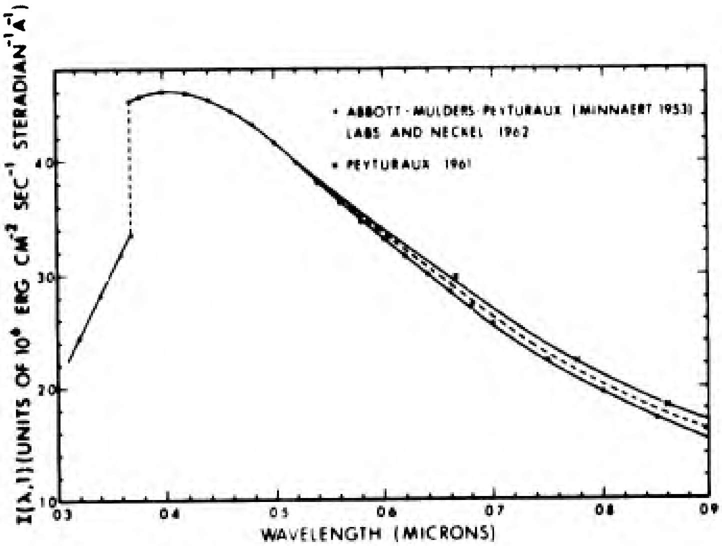

Figure 5. The Intensity of the Continuum at the Center of the Sun's Disk $I(\lambda, 1)$ as Given by Several Authors. Where they differ, the dashed line has been used

spectra by 0.055 in the logarithm. No such correction was necessary for the IR spectra. A further difficulty was that the continuum was depressed by numerous Fraunhofer lines at some wavelengths. Where this occurred we have used the Utrecht Atlast (Minnaert et al., 1940) to correct to the true continuum. However, in the region λ3660-λ4000 the continuum is completely obscured and the "true continuum" is considerably higher than that given in the Utrecht Atlas. In correcting for this we have used the discussion of Michard (1950).

A determination of $\log I_o^\lambda$, the zero-point correction that must be added to $\log I_{arb}(\lambda)$ of Figures 3 and 4, is now straightforward. As a concrete example, let us compute $\log I_o^\lambda$ at λ3539.5 for the UV spectrograms. We find that on the standard plates UV 298 and UV 300 the image of B has a photographic density of 2.59 at this wavelength. Using the appropriate characteristic curve in Figure 3 we find $\log I_{arb}(\lambda) = 1.60$ corresponding to this density. Thus,

$$\log I_o^\lambda = \log I_B(\lambda) - \log I_{arb}(\lambda) \quad , \tag{3}$$

where $\log I_{arb}$ is understood to correspond to step B. We require $\log I_B(\lambda)$ computed for this wavelength from Eq. (1). From Figure 5 we find $I(\lambda, 1) = 3.065 \times 10^6$ erg cm^{-2} sec^{-1} sr^{-1} Å^{-1}. From Pierce and Waddell (1961), we find for the $\mu_B = 0.713$ that $|I(\lambda, \mu_B)/I(\lambda, 1)| = 0.755$, and from Figure 2, $T_B = 0.525$. Since

w_B = 71.0 , Eq. (2) yields W_B = 1.82 × 10^8 cm. Substituting in Eq. (1) we find I_B = 2.27 × 10^{14} or log $I_B(\lambda)$ = 14.356. Subtracting log I_{arb} = 1.60 [Eq. (3)], we find I_o^λ = 12.756; but since this is a UV plate, we subtract 0.055 to correct for vignetting as described above. Finally, log I_o^λ = 12.701 for the UV plates at λ3539.5.

In this manner, log I_o^λ was determined for the UV plates at 35 wavelengths using steps E and B on plates UV 297, 298, 299, and 300. It was similarly determined for the IR plates at 44 wavelengths using steps F and H on plates IR 155, 156, 157, and 158. These plates were chosen because they were obtained early in the calibration run – some of the later plates were affected by light clouds. Except as noted below, there was good agreement between the determinations using different plates and steps of the wedge. The results are shown in Figure 6. The rapid increase in log I_o^λ between λ4000 and λ3000 reflects the decreasing transmission and efficiency of the optical system at short wavelengths. The rapid increase to long wavelengths beyond λ8600 is caused by the decreasing sensitivity of the HIR film at its long wavelength limit. The fluctuation of the IR curve between these extremes is due to the rapidly changing sensitivity of the HIR film with wavelength. The strong dip in sensitivity in the green is clearly apparent.

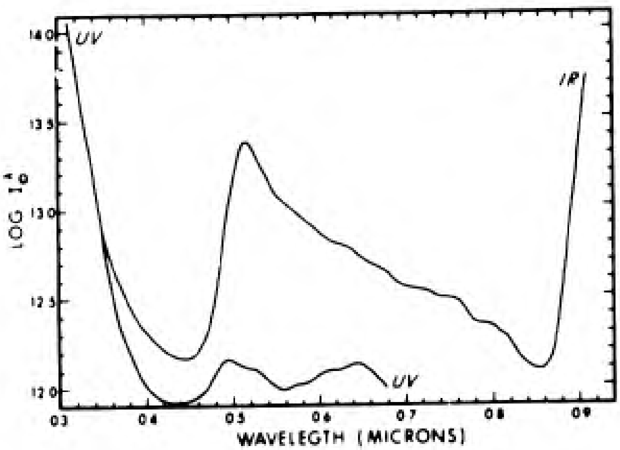

Figure 6. The Absolute Zero-Point Correction Log I_o^λ to be Applied to the Characteristic Curves in Figures 3 and 4

4.4 Absolute Intensities

To make a measurement of absolute intensity on some portion of one of the slitless spectrograms proceed as follows: Make the necessary tracings with the microphotometer and then, using identical settings, trace the standard step wedge whose densities are given in Table 4. This provides a relation between microphotometer deflection and photographic density. Enter the appropriate characteristic curve on Figure 3 or 4 with density to find the corresponding log I_{arb}. Adding to this the appropriate value of log I_{0}^{λ} from Figure 6 gives the logarithm of the absolute intensity in units of erg sec^{-1} sr^{-1} $Å^{-1}$ from a "one centimeter wide slice" of the sun's crescent. This "centimeter-wide slice" (introduced by Cillié and Menzel) is the usual quantity used in studies of the flash spectrum, and its geometry is discussed more fully by Dunn et al. (1967). The intensity of an emission line is of course found by integrating over the line profile to obtain the absolute total intensity in erg sec^{-1} sr^{-1} from the centimeter-wide slice. Two small corrections to these intensities are necessary. First, the exposure time t differs slightly from plate to plate and also from the exposure time τ of the step-attenuated standard spectra. To correct for this the final intensity must be multiplied by the factor τ/t. This is given for each plate in Tables 1 and 2, column 4. Finally, a slight additional systematic difference was found between the UV odd and even plates. To correct for this the final intensities measured on odd plates should be multiplied by the factor 1.096. In Table 1, column 5 contains a correction factor that includes both this factor and the factor τ/t.

For the slit spectra obtained during totality the intensity found as shown above must be divided by the width of the curved slit as projected onto the sun in centimeters – that is, the slit width in microns multiplied by 2.57×10^{6} cm. The resulting intensity will be in erg cm^{-2} sec^{-1} sr^{-1} $Å^{-1}$; that is, it will be per square centimeter rather than per "centimeter-wide slice". The width of the curved slits vary along their length and must be measured at the appropriate place. Because some of the totality spectra have much longer exposure times than the standard spectra on which the calibration is based, some correction for reciprocity failure may be required.

5. CONCLUSIONS

Characteristic curves calibrated in absolute units, and other data necessary to make absolute spectrophotometric measurements on the 1962 eclipse spectra have been presented. While some estimates of the accuracy of this calibration might be given, the most satisfactory check on the magnitude of possible systematic or random errors will come from photometric studies based upon it (Dunn et al., 1967; Henze, 1967). Preliminary studies show that the IR and UV data are consistent where they overlap, and the chromospheric line intensities show a smooth decrease with plate number (height).

The collection of plates is kept at the Sacramento Peak Observatory, Sunspot, New Mexico, 88349. Persons desiring to consult them should contact the Director, Dr. John W. Evans.

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13. ABSTRACT

This report contains the information needed to make spectrophotometric measurements on the numerous "jumping-film" spectrograms obtained at the total solar eclipse of 4 and 5 February 1962 at Lae, New Guinea, by a joint expedition of the High Altitude Observatory, the National Bureau of Standards, and the Sacramento Peak Observatory (AFCRL). It includes a brief description of the instrument, a catalog describing each of the spectrograms, characteristic curves for the photographic emulsions used, and a procedure for reducing photometric measurements to absolute intensity.

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