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Observations of the Corona at the Eclipse of 1983 June 11
I Temperature and Rotation of the Corona from 5303A and 6374A profiles

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ABSTRACT

During the total solar eclipse of 1983 June 11, coronal spectra were obtained in the 5303A (Fe XIV) line using a multislit spectrograph at a dispersion of 2 17A mm^{-1} The line profiles measured at 113 locations from 1 04 to 1 24 Ro have half widths ranging from 0 6A to 1 4A The most frequent width of 0 9A corresponds to a temperature of 3 1 x 10^{6}K Since according to the ionization equilibrium calculations a temperature of 2 x 10^{6}K is typical of regions emitting 5303A radiation we ascribe the difference between our observed and the latter temperatures to random turbulent velocities of 18 4 Km s^{-1} Comparing this with the value of 32 4 Km s^{-1} derived for the 1980 eclipse, it appears that the random turbulent velocity may be cycle dependent The line of sight velocities on most locations are within ±5 Km s^{-1} indicating that the corona is quiet We had set up another experiment with a second multislit spectrograph for the 6374A line spectra and the coronal rotation velocities derived from these profiles have a mean value of 3 5 Km s^{-1} These observations confirm the findings of the 1980 eclipse by the Institute s team, that the corona does not show any localized differential mass motions and that it corotates with the photospheric layers

Key Words: solar corona - green and red coronal line profiles coronal temperatures - rotation of the solar corona

1 Introduction

The advantage of using a multislit spectrograph to study the emission line profiles of the forbidden lines in the coronal spectrum at a solar eclipse has been well illustrated by the earlier efforts of the Institute's team during the eclipse of 1980 February 16 (Singh, Bappu and Saxena, 1982) By a careful choice of the spatial locations of the slits on the coronal image during an eclipse, it is possible to map out the coronal temperature distribution in two dimensions in the sky plane with a good coverage within the corona A good amount of data have now been collected using this technique for the two most commonly used lines, namely 5303A (Fe XIV) and 6374A (Fe X) The Kitt Peak astronomers (Livingston et al 1980) observed the 5303A line, while the Indian team used the 6374A line at the eclipse of 1980 Although in principle this information is valuable as it belongs to the same eclipse, these cannot be pooled to enhance the information on the corona, since the spectra in each line pertain to dissimilar locations of the slits on the corona in the two cases. Simultaneous observations using two of the coronal emission lines would be the direct means for understanding the ionization equilibrium conditions in the corona. With this in mind, we used the multislit technique to obtain spectra simultaneously in the two lines 5303 A and 6374 A during the present eclipse. Unfortunately our spectra in 6374 A are underexposed and hence are not very useful. We report here in the first part, the result of the analysis of the 5303 A line spectra. In the second part we present the results of the coronal rotation velocities derived from the 6374 A spectra obtained from another multislit spectrograph set up and operated by us in the same camp. Since the latter do not have good spectral resolution we are unable to use them to derive the temperatures.

2. Coronal Temperatures from Multislit Spectrograph I

2.1 Instruments

We set up a two mirror 30cm coelostat with zerodur optics and fed the sunlight onto an objective of 15 cm aperture and 225cm focal length which formed the image of the sun in the plane of the five slits of the spectrograph. These 60µm wide slits were separated by 5mm and this corresponds to 7.8 arcmin on the solar image. The coelostat was adjusted to direct the sunlight so that the solar equator was approximately in the direction of the length of the slits. We used a 600 lines mm^{-1} grating blazed at 2.0µm in the first order along with a 225cm focal length achromatic doublet in the Littrow mode that gave a dispersion of 2.17A mm^{-1} in the third order. We mounted a beam splitter in front of the slits and this enabled us to register the comparison spectra along with the coronal spectrum. We used two identical single-stage Varo image intensifier tubes with a gain of 20 and an effective aperture of 30mm and recorded the spectra in 5303A and 6374A. Two interference filters of 10A bandwidth with peak transmission at 6374A and 5303A were mounted in front of the respective image tubes that cut down the undesired continuum. We used a turret plate holder carrying six photographic plates at one time and this made a quick change of plates after each exposure possible. It also had the provision of keeping the emulsion in contact with the fibreoptic face of the image intensifier during the exposures.

2.2 Observations

We established the camp at Tanjung Kodok (Long. 112° 21' 28" E; Lat. 6° 51' 54" S) on a piece of elevated rocky land projecting into the Java sea and located close to Paciran, a village in East Java. This site was close to the central path of totality. The eclipse occurred around 1135 hours local time There were rains for two days prior to the day of the eclipse which stopped in the late afternoon of June 10 The eclipse day started with skies with broken clouds which thinned out with time and at the time of totality the corona was seen through a thin veil of cloud

With the multislit spectrograph we obtained four spectra in each wavelength during the totality phase with exposures 10, 15, 30 and 60 secs on Kodak 103a-D emulsion We carried back home these plates and later developed them in D 19 developer at 20°C for five minutes along with the calibration from a Hilger step wedge obtained through the same image intensifier tube at the Kodaikanal 18m spectrograph Unfortunately, the coronal spectra in the 6374A line were underexposed and we could not use them But the neon spectrum of 6382 9A line obtained along the length of the five slits on these plates enabled the evaluation of the instrumental line profiles at several points along each slit We derived the mean value of 0 35 ± 0 04A for the full width at half maximum (FWHM) of the instrumental profiles from several of these profiles which we used for the evaluation of the coronal line widths We made microdensitometer scans of the 5303A line spectra of the 60 sec exposure plate, using a projected slit of 5 5x9 arcsec with the successive scans separated by 9 arcsec along the slit We then converted these density values to intensities via the photometric calibration The mean transmission curve of the interference filter determined by us was used to operate on the intensity curve of the green line corresponding to each point along the slit This procedure gave the observed profile of the coronal line The FWHM for these profiles were now corrected for the instrumental line width using the mean value of 0 35 ± 0 04A assuming that both profiles are Gaussian in shape

2.3 Results

From these line profiles we have measured the widths of the green coronal line at 113 locations ranging from 1.04 to 1 24Ro within the corona and we have presented these values in Table 1 The position angle measured from the north point of the projected axis of the solar rotation and the radial distance from the centre of the disc are given in columns 2 and 3 Column 4 contains the FWHM values corrected for the instrumental profile and column 5 contains the turbulent velocities derived by assuming a coronal temperature of 2×10^6K In column 6 are the equivalent temperature values if the FWHM is ascribed entirely to thermal broadening The peak values of the brightness of the line in arbitrary units are listed in column 7 and the relative line of-sight velocities in column 8

Table 1. Line widths, (FWHM) turbulent velocities (V_t) and intensities (I_l) from the green coronal line 5303A.

No.	Position angle θ	R/R⊙	FWHM A	V_t Km s^{-1}	Temp. x10^{-6}K	I_1	V Km s^{-1}
1	2	3	4	5	6	7	8
			I Slit				
1	70.53	1.040	0.832	14.2	2.7	235	-
2	70.85	1.048	0.811	12.8	2.5	231	-
3	71.16	1.056	0.819	13.3	2.6	212	-
4	71.46	1.064	0.776	9.9	2.3	190	-
5	71.76	1.072	0.667	0.0	1.7	166	-
6	72.06	1.080	0.737	5.5	2.1	162	-
7	72.35	1.088	0.763	8.7	2.3	123	-
8	72.64	1.096	0.936	20.3	3.4	97	-
9	72.92	1.104	0.876	17.0	2.9	81	-
10	73.20	1.112	0.854	15.6	2.8	77	-
11	73.47	1.120	0.884	17.4	3.0	58	-
12	73.75	1.128	0.858	15.9	2.9	53	-
13	74.01	1.136	0.854	15.7	2.8	50	-
14	74.28	1.144	0.798	11.8	2.5	47	-
15	74.54	1.152	0.823	13.6	2.6	44	-
16	74.80	1.160	0.810	12.8	2.5	37	-
17	75.04	1.168	0.841	14.2	2.7	32	-
18	75.29	1.176	0.923	19.7	3.3	28	-
19	75.54	1.185	0.815	13.1	2.6	28	-
20	75.78	1.193	0.876	17.0	3.0	23	-
21	76.02	1.201	0.962	21.7	3.6	19	-
			II Slit				
22	100.06	1.040	0.771	9.5	2.3	224	0.7
23	100.12	1.049	0.624	0	1.5	187	-1.2
24	100.19	1.059	0.685	0	1.8	142	0
25	100.25	1.068	0.754	7.7	2.2	133	-2.5
26	100.31	1.078	0.858	15.9	2.9	112	-2.0
27	100.37	1.087	0.602	0	1.4	133	0
28	100.43	1.097	0.628	0	1.5	124	+1.7
29	100.48	1.107	0.802	12.1	2.5	92	0
30	100.54	1.116	0.767	9.1	2.3	89	-3.2
31	100.59	1.126	0.884	17.5	3.0	60	+2.5
32	100.65	1.135	0.832	14.2	2.7	49	-1.2
33	100.70	1.145	0.897	18.2	3.1	31	3.7
34	100.75	1.155	0.867	16.5	2.9	28	0.5
35	100.81	1.164	0.910	18.9	3.2	23	+2.5

1	2	3	4	5	6	7	8
			III Slit				
36	127 62	1 043	0 928	19 9	3 3	56	+1 2
37	127 43	1 052	0 949	21 0	3 5	53	-2 0
38	127 25	1 061	0 841	14 8	2 7	50	0
39	127 07	1 070	0 824	13 7	2 6	49	+1 0
40	126 89	1 079	1 079	27 3	4 5	46	2 7
41	126 72	1 088	1 144	30 2	5 0	44	5 6
42	126 55	1 097	0 893	18 0	3 1	44	10 0
43	126 38	1 106	1 270	35 5	6 2	41	-7 8
44	126 22	1 115	1 232	34 0	5 9	39	+5 6
45	126 06	1 124	1 153	30 6	5 2	39	-2 9
46	125 90	1 134	0 876	17 0	3 0	39	-0 5
47	125 74	1 142	0 850	15 4	2 8	38	-3 7
48	125 59	1 152	0 954	21 3	3 5	39	-0 5
49	125 43	1 161	1 006	23 9	3 9	36	-3 0
50	125 29	1 170	1 010	24 1	4 0	31	0
51	125 14	1 179	0 780	10 3	2 4	29	+1 0
52	125 00	1 188	1 232	34 0	5 9	27	-4 6
53	124 85	1 198	0 906	18 8	3 2	26	-0 5
54	124 71	1 207	0 893	18 0	3 1	28	-0 5
55	124 57	1 216	0 876	17 0	2 9	25	-3 4
			IV Slit				
56	162 40	1 045	1 232	34 0	5 9	27	-
57	161 96	1 050	1 071	27 0	4 4	27	-
58	161 54	1 056	1 149	30 4	5 1	22	-
59	161 11	1 061	1 258	35 0	6 1	19	-
60	159 86	1 079	1 397	40 7	7 5	15	-
			V Slit				
61	231 16	1 039	0 910	18 9	3 2	94	-
62	231 60	1 045	0 832	14 2	2 7	84	
63	232 04	1 050	0 837	14 6	2 7	72	
64	232 46	1 055	0 884	17 5	3 0	67	
65	232 89	1 061	0 893	18 0	3 1	68	-
66	233 31	1 067	0 876	17 0	3 0	75	-
67	233 73	1 073	0 893	18 0	3 1	74	-
68	234 14	1 079	0 936	20 4	3 4	65	-
69	234 54	1 085	1 006	23 9	3 9	44	-
70	234 95	1 090	1 188	32 1	5 5	43	
71	235 34	1 096	1 197	32 5	5 5	41	-
72	237 27	1 127	0 876	17 0	3 0	26	-
73	237 64	1 133	0 984	22 8	3 8	26	-
74	238 01	1 140	0 910	18 9	3 2	27	-
75	238 37	1 146	1 223	33 6	5 8	21	-

1	2	3	4	5	6	7	8
76	238 74	1 152	1 296	36 6	6 5	19	
			VI Slit				
77	266 38	1 043	0 746	6 8	2 1	394	+2 5
78	266 57	1 052	0 971	22 2	3 6	354	0 0
79	266 75	1 061	0 737	5 5	2 1	303	4 9
80	266 93	1 070	0 746	6 8	2 1	257	+2 5
81	267 10	1 079	0 837	14 6	2 7	275	2 5
82	267 28	1 088	0 837	14 6	2 7	251	-2 5
83	267 45	1 097	0 789	11 0	2 4	194	-4 6
84	267 62	1 106	0 802	12 1	2 5	155	+2 0
85	267 78	1 115	1 062	26 5	4 4	133	0 7
86	268 26	1 143	0 932	20 1	3 4	94	0
87	268 41	1 152	0 806	12 4	2 5	74	1 7
88	268 56	1 161	0 819	13 3	2 6	77	2 5
89	268 71	1 170	0 763	8 7	2 3	83	1 5
90	268 86	1 179	0 902	18 5	3 1	61	1 0
91	269 00	1 189	0 728	3 9	2 1	53	-2 0
92	269 15	1 198	0 867	16 5	2 9	43	-1 2
93	269 29	1 207	0 780	10 3	2 4	36	0
94	269 43	1 216	0 884	17 5	3 0	30	0
95	269 57	1 225	0 850	15 4	2 8	34	1 2
96	269 70	1 234	0 910	18 9	3 2	31	-4 4
			VII Slit				
97	293 94	1 040	0 919	19 4	3 3	76	0 5
98	293 88	1 049	0 889	17 8	3 1	61	-0 5
99	293 81	1 059	0 910	18 9	3 2	61	2 5
100	293 75	1 068	0 927	19 9	3 3	52	-1 0
101	293 69	1 078	0 832	14 2	2 7	44	-3 2
102	293 63	1 087	0 932	20 1	3 4	39	+1 0
103	293 57	1 097	0 906	18 7	3 2	33	2 0
104	293 52	1 106	0 811	12 8	2 5	28	+6 4
105	293 46	1 116	0 989	23 1	3 8	27	+3 9
106	293 40	1 126	1 249	34 7	6 0	21	3 4
			VIII Slit				
107	323 47	1 040	0 732	4 7	2 1	54	-
108	323 15	1 048	0 893	18 0	3 1	38	-
109	322 84	1 056	0 606	0	1 4	36	-
110	322 54	1 064	0 641	0	1 6	36	-
111	322 24	1 072	0 715	0	1 9	26	-
112	321 94	1 080	0 876	17 0	2 9	19	-
113	321 65	1 088	0 836	14 5	2 7	15	-

2 3 1 Line Widths

We have shown in Fig 1 a typical line profile of the 5303A line and the best Gaussian fit to these data points The FWHM measured from the curves drawn with free hand agree with the corresponding Gaussian fits within 3 percent We present in Fig 2 the FWHM values so derived for the green coronal line for the different locations within the corona The line widths vary from 0 6A to 1 4A and if wholly ascribed to thermal broadening would correspond to a temperature range of 1 4 6 5 x 10^6K The frequency distribution of the line widths presented in Fig 3 shows that the most frequent line width is around 0 9A

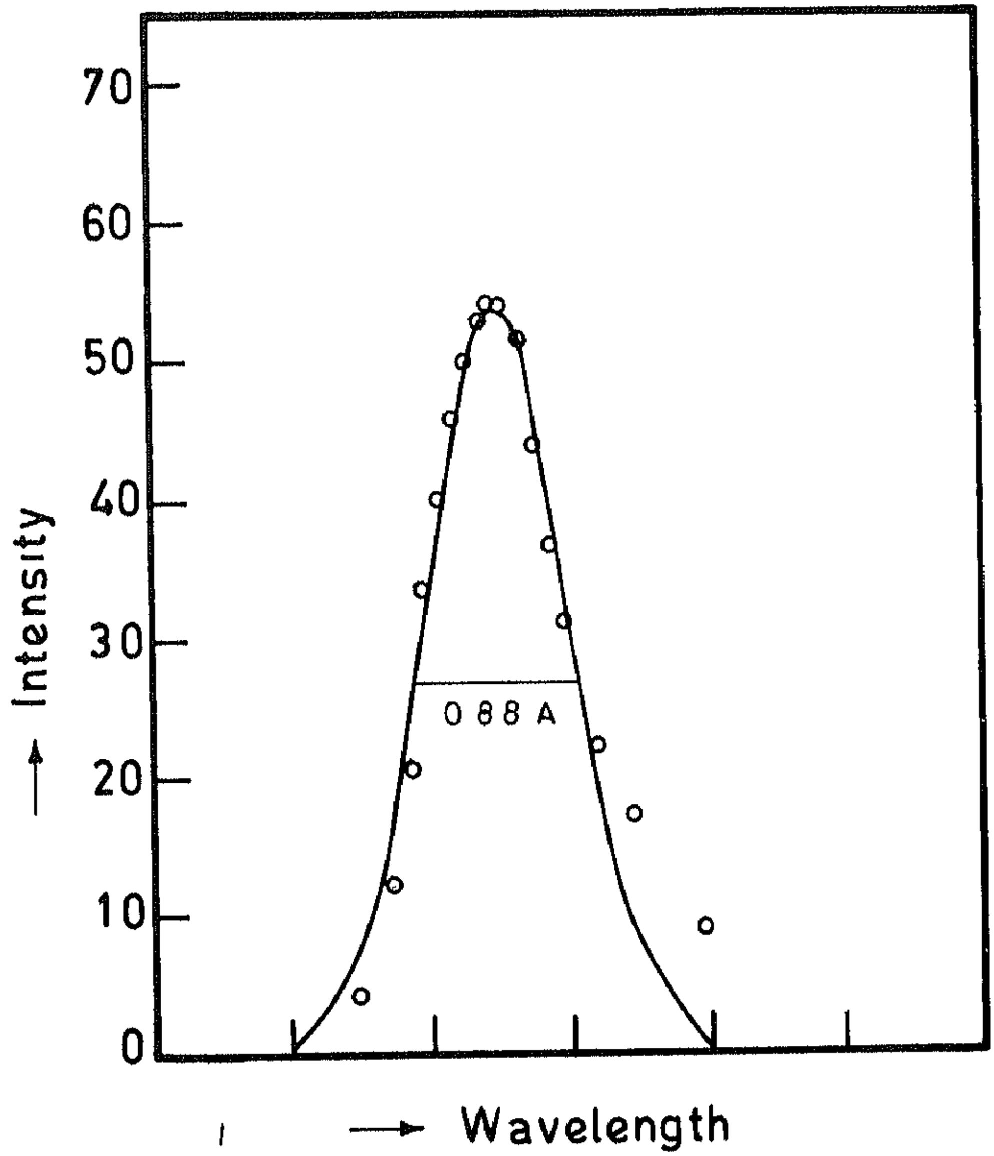

Figure 1 A typical observed line profile of 5303A line Full line curve is the best Gaussian fit to these data points

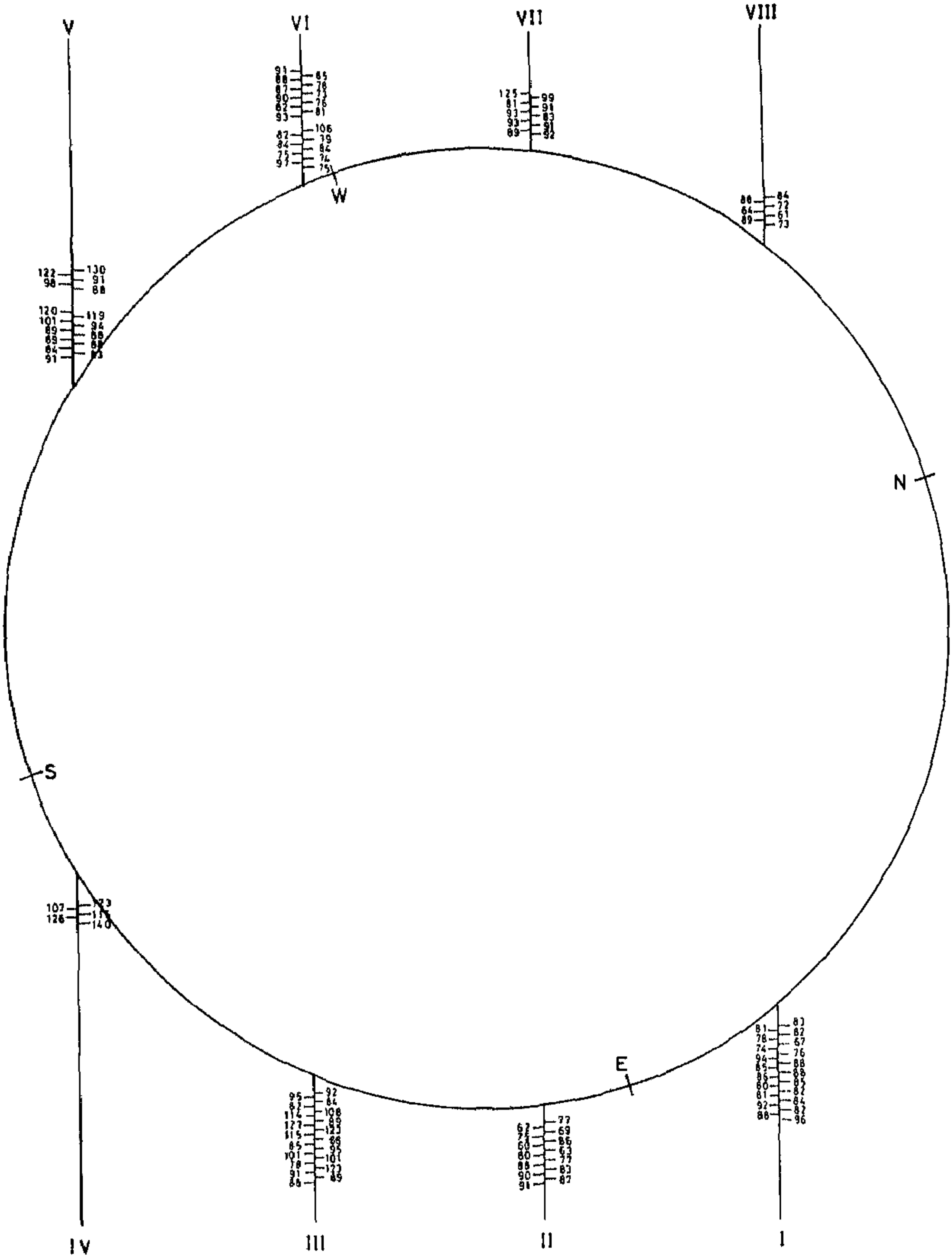

Figure 2. The numbers represent the true line widths of the 5303A line in units of 10^{-2} A at various locations within the corona. I, II, III, etc. represent the positions of the slits of the multislit spectrograph on the solar image during the time of the eclipse

2 3 2 Line intensities

We have used the measures of the relative intensity of the peak of the line to study the emission gradients of the K corona using the data of slit, I, II, III and VI These are plotted in Fig 4 The gradients are quite steep except for slit III There is good qualitative agreement between these gradients and the brightness distribution seen in the broad band photographs of L Lacey and M McGrath of the High Altitude Observatory obtained with a radially graded filter from a camp close to ours The slow gradient at position angle 124°-128° is seen to be over the huge helmet streamer at the south east limb

2 3 3 Line of sight velocities

In the absence of a comparison line for the 5303A spectra we have measured the Doppler shift with reference to a local fiducial mark etched on the plate Assuming a zero residual velocity along the whole length of the slit, we have derived the line-of-sight velocities with reference to this local zero value for the two central slits, for which there are sufficient data points The line of-sight velocities on most of the locations turn out to be within ±5 Km s^{-1} indicating that the corona is remarkably quiet as against the large scale mass motions reported by Delone and Makarova (1969) earlier or by Desai, Chandrasekhar and Angreji (1982) for the 1980 eclipse in India

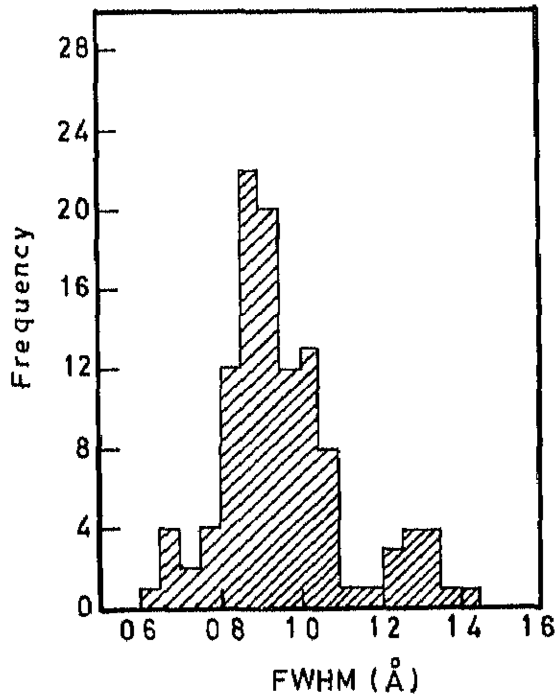

Figure 3 The frequency distribution of the line width of 5303A

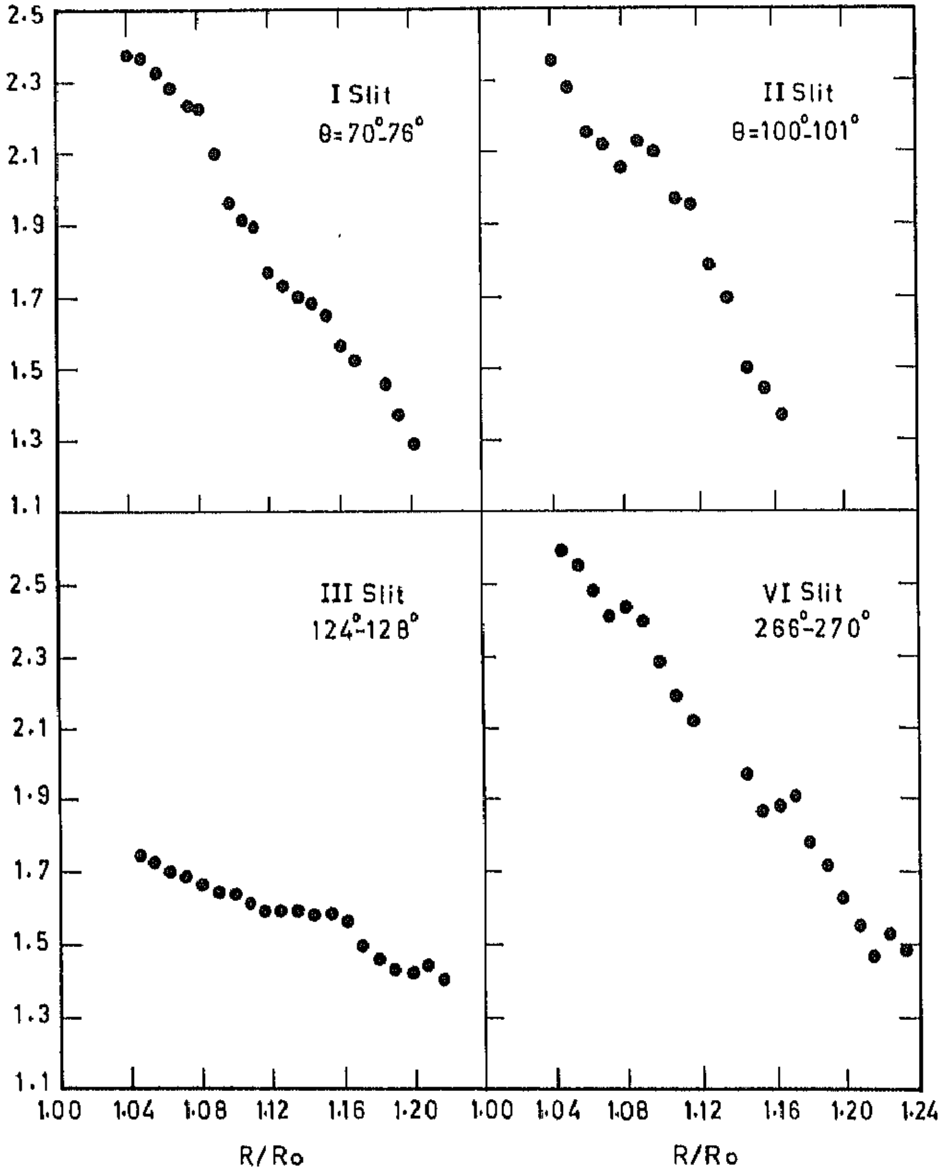

Figure 4. Intensity of 5303A line in logarithmic units against radial distance. The position angle is indicated for each curve

2.3.4. Discussion of the results

Our measures show that the line widths vary from 0.6A to 1.4A. If thermal broadening is the only contributor to the line widths then, with the help of the standard kinetic temperature relation one would arrive at a temperature of 1.4×10^{6} K for 0.6A and 6.5×10^{6}K for 1.4A. The most frequent line width of 0.9A would imply a kinetic temperature of 3.1×10^{6}K. According to the ionization equilibrium calculations of Jordan (1969), the (Fe XIV) ions are most abundant at the temperature of 2.0×10^{6}K while Jain and Narain (1978) obtain peak abundance at 2.5×10^{6}K for these ions from their calculations. If we assume that this temperature predicted by the calculations represents the temperature of the regions emitting the 5303A radiation, then the corresponding line width is found to be always lower than the observed value In the customary way, we attribute the excess broadening noticed to the turbulent velocities of the radiating ions in the corona We have calculated the turbulent velocities for both the temperature values of Jordan (1969) as well as of Jain and Narain (1978) and these turn out to be 18 4 Km s^{-1} and 13 8 Km s^{-1} respectively (Table 2) By similar arguments one would arrive at the values of 32 4 Km s^{-1} and 33 3 Km s^{-1} for the turbulent velocities from the line profiles of 6374A line of the 1980 eclipse (Singh, Bappu and Saxena 1982) corresponding to the Jordan's (1969) and Jain and Narain's (1978) calculations (Table 2) The mean values of the turbulent velocities turn out to be 33 Km s^{-1} and 16 Km s^{-1} for the 1980 and 1983 eclipses respectively Knowing that the corona in 1980 was more active than in 1983, one is tempted to associate large value of turbulent velocity with an epoch of high solar activity and a smaller value with an epoch of low solar activity

Table 2 Temperatures and turbulent velocities (V_t Km s^{-1}) from theoretical calculations

Eclipse	Emission line	FWHM (Mean value present study)	Jordan (1969)		Jain & Narain (1978)	
			Temp °K	V_t Km s^{-1}	Temp K	V_t Km s^{-1}
June 11, 1983	5303A	0 9A	2.0 $\times 10^6$	18 4	2 5 $\times 10^6$	13 8
February 16, 1980	6374A	1 3A	1.0 $\times 10^6$	32 4	0 8 $\times 10^6$	33 3

3 Coronal Rotation from Multislit Spectrograph II

3 1 Instruments

In the same camp we had set up one more multislit spectrograph for photographing spectra in the 6374A line of (Fe X) with the slits oriented approximately along the direction of the polar diameter of the solar image A 30cm coelostat directed the sunlight to an f/10 achromatic objective of 10cm aperture, forming a 9 2mm diameter solar image on the slit plane of the spectrograph provided with three slits each 80 um wide and separated by 5mm from its neighbour The central slit was close to the poles of the sun The spectrograph with a 600 lines mm^{-1} grating and 100 cm focal length achromat functioned in the Littrow mode providing a dispersion of 2 68A mm^{-1} in the fourth order red region We used to a 35 mm film transport carrying Kodak 103a E film mounted in the focal plane to photograph the spectra We also recorded simultaneously neon comparison spectra to provide the wavelength calibration

Table 3. Wavelength of red coronal line (6374A) and the line-of-sight velocities

Sl. No.	Position angle	R/R⊙	Wavelength in A	Km s^{-1}
1	2	3	4	5
		East (III slit)		
1	85.73	1.183	6374.544	- 2.8
2	86.71	1.175	6374.469	- 6.4
3	87.69	1.167	6374.308	-13.9
4	88.70	1.159	6374.442	- 7.9
5	89.71	1.152	6374.523	- 3.8
6	90.74	1.145	6374.512	- 4.3
7	91.78	1.138	6374.485	- 5.6
8	92.83	1.132	6374.523	- 3.8
9	93.89	1.126	6374.555	- 2.3
10	94.96	1.120	6374.512	- 4.3
11	96.05	1.115	6374.394	- 9.9
12	97.14	1.110	6374.496	- 5.1
13	98.24	1.106	6374.641	+ 1.7
14	99.35	1.103	6374.576	- 1.3
15	100.47	1.099	6374.533	- 3.3
16	101.59	1.096	6374.544	- 2.8
17	102.72	1.094	6374.523	- 3.8
18	103.86	1.092	6374.490	- 5.3
19	105.00	1.090	6374.448	- 7.4
20	106.14	1.088	6374.603	0.0
21	107.28	1.087	6374.576	- 1.3
22	108.43	1.087	6374.619	+ 0.7
23	109.57	1.087	6374.630	+ 1.2
24	110.71	1.087	6374.619	+ 0.7
25	111.86	1.088	6374.598	- 0.3
26	113.00	1.090	6374.630	+ 1.2
27	114.14	1.092	6374.565	- 1.8
28	115.29	1.094	6374.496	- 5.1
		II Slit Southpole		
29	199.00	1.033	6374.576	- 1.3
30	199.00	1.054	6374.523	- 3.8
31	199.00	1.076	6374.528	- 3.6
32	199.00	1.098	6374.624	+ 1.0
		West I Slit		
33	268.70	1.159	6374.748	+ 6.8
34	269.71	1.152	6374.737	+ 6.3
35	270.74	1.145	6374.710	+ 5.0

1	2	3	4	5
36	271 78	1 138	6374 598	0 3
37	272 83	1 132	6374 737	+ 6 3
38	273 89	1 126	6374 748	+ 6 8
39	274 96	1 120	6374 689	+ 4 0
40	276 05	1 115	6374 699	+ 4 5
41	277 14	1 111	6374 630	+ 1 2
42	278 24	1 106	6374 716	+ 5 3
43	279 35	1 103	6374 817	+10 0
44	280 47	1 099	6374 704	+ 4 8
45	281 59	1 096	6374 737	+ 6 3
46	282 72	1 093	6374 780	+ 8 3
47	283 86	1 091	6374 694	+ 4 2
48	284 99	1 090	6374 662	+ 2 7
49	286 14	1 088	6374 592	- 0 6
50	287 28	1 087	6374 630	+ 1 2
51	288 43	1 087	6374 619	+ 0 7
52	289 57	1 087	6374 672	+ 3 2
53	290 72	1 087	6374 694	+ 4 2
54	291 86	1 088	6374 619	+ 0 7
55	293 00	1 090	6374 496	- 5 1
56	294 14	1 091	6374 592	0 6
57	295 28	1 093	6374 640	1 7

3 2 Observations

Of the two spectra obtained with exposures 10s and 200s of the 6374A line during the totality phase of the eclipse, we have chosen the 200s spectra for analysis We made microdensitometer scans of the spectra using a scanning slit of 17x17 arcsec^2 on the plate with the successive scans separated by 17 arcsec along the slit Using the neon line 6382 99A as the reference, we computed the wavelength of the coronal red line at 57 locations ranging from 1 09 to 1 17R$_\odot$

3 3 Results

We present these data in Table 3 Of the 57 data points, 28 are on the east limb, 25 on the west limb and the remaining four are near the south pole The position angle measured from the north point of the projected axis of the sun and the radial distance from the centre of the disc are given in columns 2 and 3 The values of the wavelengths of the red line are tabulated in column 4 Column 5 contains the line of sight velocities we have derived using the mean value of 6374 604A for the wavelength of the red line. These velocities vary between + 10 Km s^{-1} and - 14 Km s^{-1} and most of the locations have velocities less than ± 5 Km s^{-1} which agree with our values obtained from the 5303A line spectra (section 2.3.3). The mean wavelength values of the red line on the east limb is 6374.530 ± 0.04A and on the west limb is 6374.678 ± 0.04A. The difference of 0.148A corresponds to a coronal rotation value of 3.5 ± 1 Km s^{-1}. These results would permit us to conclude that the corona does not show any localized differential mass motion and rotates with a speed comparable to that of the photospheric layers. This is in agreement with the findings of Livingston and Harvey (1982).

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