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A study of coronal streamers during the total solar eclipse of 1980 February 16

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Abstract. Procedure outlined by Saito & Billings has been used for deriving the three dimensional configurations of 17 coronal streamers from the photographs of total solar eclipse of 1980 February 16. Almost all streamers were traced to their origin in some optical feature found on the synoptic map of the sun.

Key words: coronal streamers—total solar eclipse---polarization measurements

1. Introduction

As is well known, the coronal streamers photographed during any total solar eclipse are oriented into various directions in space. The angle, which the axis of the streamer makes with the plane of the sky, is very useful in determining the orientation of the streamer and the place of its origin.

The determination of the three dimensional form of the coronal features, using polarization measurements, was attempted by several observers during the past eclipses : Schmidt (1953), Saito & Billings (1964), Saito (1972), Nikolsky *et al.* (1977). The principle involved is to compare the polarization in the streamer with the theoretical polarization obtained by using the theory of scattering by an elementary volume of coronal matter. This type of analysis assumes that the presence of the scattering matter outside the streamer can be neglected and the extent of the ray along the line of sight is small enough in comparison with the distance of its elements from the sun (Nikolsky *et al.* 1977).

Here we study the orientation of the coronal streamers in space and to fix their heliographic coordinates wherever possible, for the solar corona of 1980 February 16, by using the measured polarization values. These were obtained using a double polarigraph (Anthony Raju 1981) at two wavelengths : blue (λ4200 Å) and red (λ7000 Å). As the ray structure was clearly seen in the red (Anthony Raju & Abhyankar 1986) we have used the photographs taken in red to study the structure of the coronal streamers.

Since 1980 was the year of maximum solar activity, there were many active features present in the solar corona of 1980 February 16. The various streamers present in the corona are shown in the drawing of the corona (figure 1) which is based on the photograph of the corona taken by J. L. Street & L. B. Lucy of high altitude observatory through a graded filter.

2. Polarization in the streamer

The theoretical degree of polarization, P, of the light scattered by an electron at any point in the corona when viewed from the earth is $P = (J_t - J_r)/(J_t + J_r)$, where J_t and J_r are the tangential and the radial components of the scattered light. These can be expressed as (Saito 1970; van de Hulst 1950)

$$J_t = (3/8)\, B_{\odot}\, \sigma\, A,$$

$$J_r = (3/8)\, B_{\odot}\, \sigma\, (A \cos^2 \theta + B \sin^2 \theta).$$

Hence the polarization

$$P = \frac{A - B}{A\,(2 \operatorname{cosec}^2 \theta - 1) + B}. \qquad ...(1)$$

Here $B_{\odot}$ is the average brightness of the solar disc, σ the cross section of electron scattering and θ the angle between the line of sight and the radius vector to that point. The coefficients A and B defined by van de Hulst (1950) depend on the

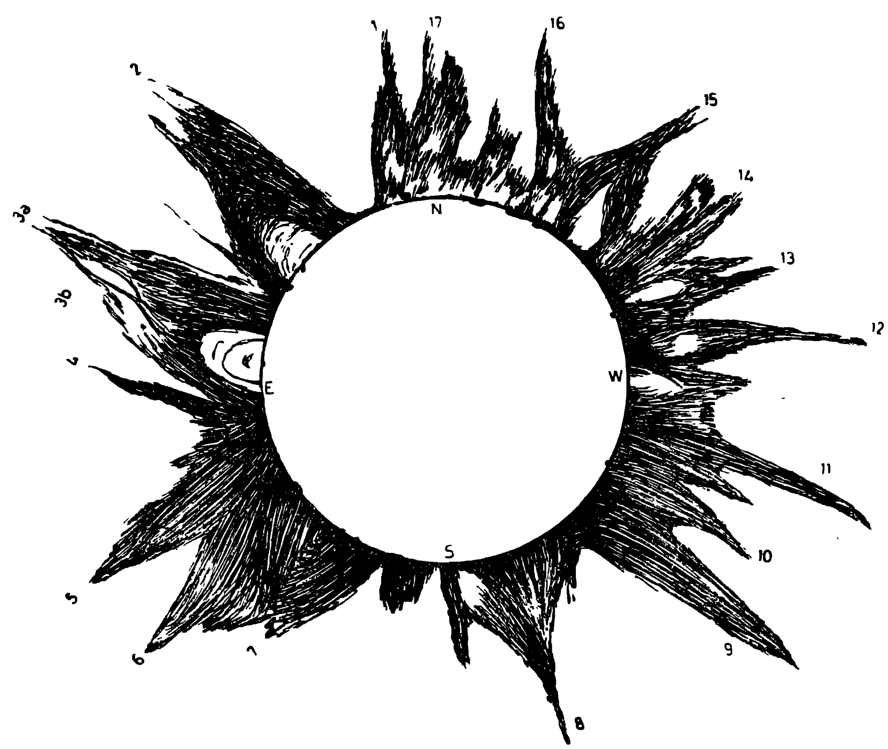

Figure 1. Drawing of the streamers in the corona of the total solar eclipse of 1980 February 16. Position of limb prominences is indicated by black dots.

limb darkening constant Q which we have taken to be 0.485 for the red wavelength of λ 7000 Å.

Using the values of A and B, the values of P were calculated for each value of θ for various values of r, the projected solar distance. These are shown by dashed lines in figures 2 and 3 for $\lambda = 7000$ Å corresponding to our red photographs.

In order to compare the observed values of the polarization with the theoretical values, the polarization in the streamer alone should be determined. For this the background polarization was removed from the polarization of K-corona in the following way.

The observed polarization of K-corona in the streamer $P_{\mathrm{K,obs}}$ is

$$P_{\mathrm{K,obs}} = \frac{(S_t + B_t) - (S_r + B_r)}{(S_t + B_t) + (S_r + B_r)}, \qquad \ldots(2)$$

where S and B denote the intensities in the streamer and background, and the subscripts t and r denote the transverse and radial components, respectively. Now

$$P_S = \frac{S_t - S_r}{S_t + S_r}, \quad P_B = \frac{B_t - B_r}{B_t + B_r}, \qquad \ldots(3)$$

$$P_{\mathrm{K,obs}}\,(S + B) = P_S\, S + P_B\, B, \qquad \ldots(4)$$

and

$$S = K_{\mathrm{obs}} - B. \qquad \ldots(5)$$

Therefore from equations (2)–(5) we get the polarization in the streamer

$$P_S = P_{\mathrm{K,obs}} \left[1 + \frac{(P_{\mathrm{K,obs}} - P_B)/P_{\mathrm{K,obs}}}{(K_{\mathrm{obs}} - B)/B} \right]; \qquad \ldots(6)$$

Since there is sufficient evidence for the presence of a coronal hole in the southern hemisphere and the polarization values in this direction drop off very rapidly, the values of the polarization in this direction, at position angle 160°, were taken as the polarization of the background. Similarly the intensity in the same direction was taken as the intensity of the background. Then the polarization in the streamer alone was calculated using equation (6) for each streamer at various values of r. Altogether 17 streamers were identified at various position angles as shown in figure 1. The polarization in these streamers are plotted along with the theoretical curves in figures 2 and 3. The specimen values of the observed polarization of K-corona ($P_{\mathrm{K\cdot obs}}$), polarization of background (P_B), intensity of K-corona ($K_{,\mathrm{obs}}$), the intensity of the background (B) and finally the polarization of the streamer (P_S) for one streamer are shown in table 1.

3. Heliographic coordinates of the streamers

Comparing the polarization values of the streamer with the theoretical curves of polarization for various values of θ, the value of θ for each streamer was obtained. It was seen that often one streamer had to be assigned more than one value of θ, one for the lower portion of the curve and the other for the upper portion of the

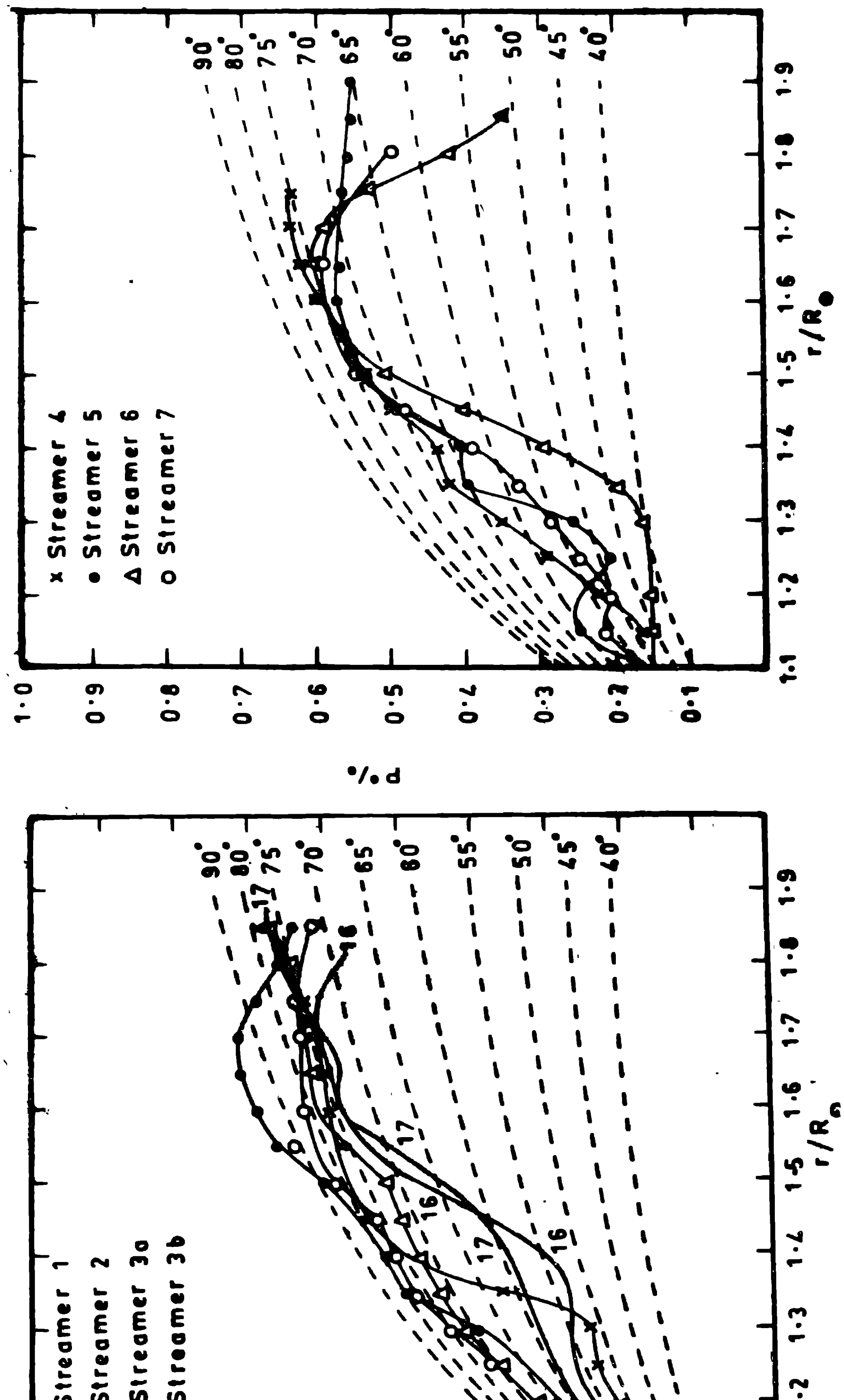

Figure 2. Observed and theoretical polarization in streamers 1 to 7, 16 and 17.

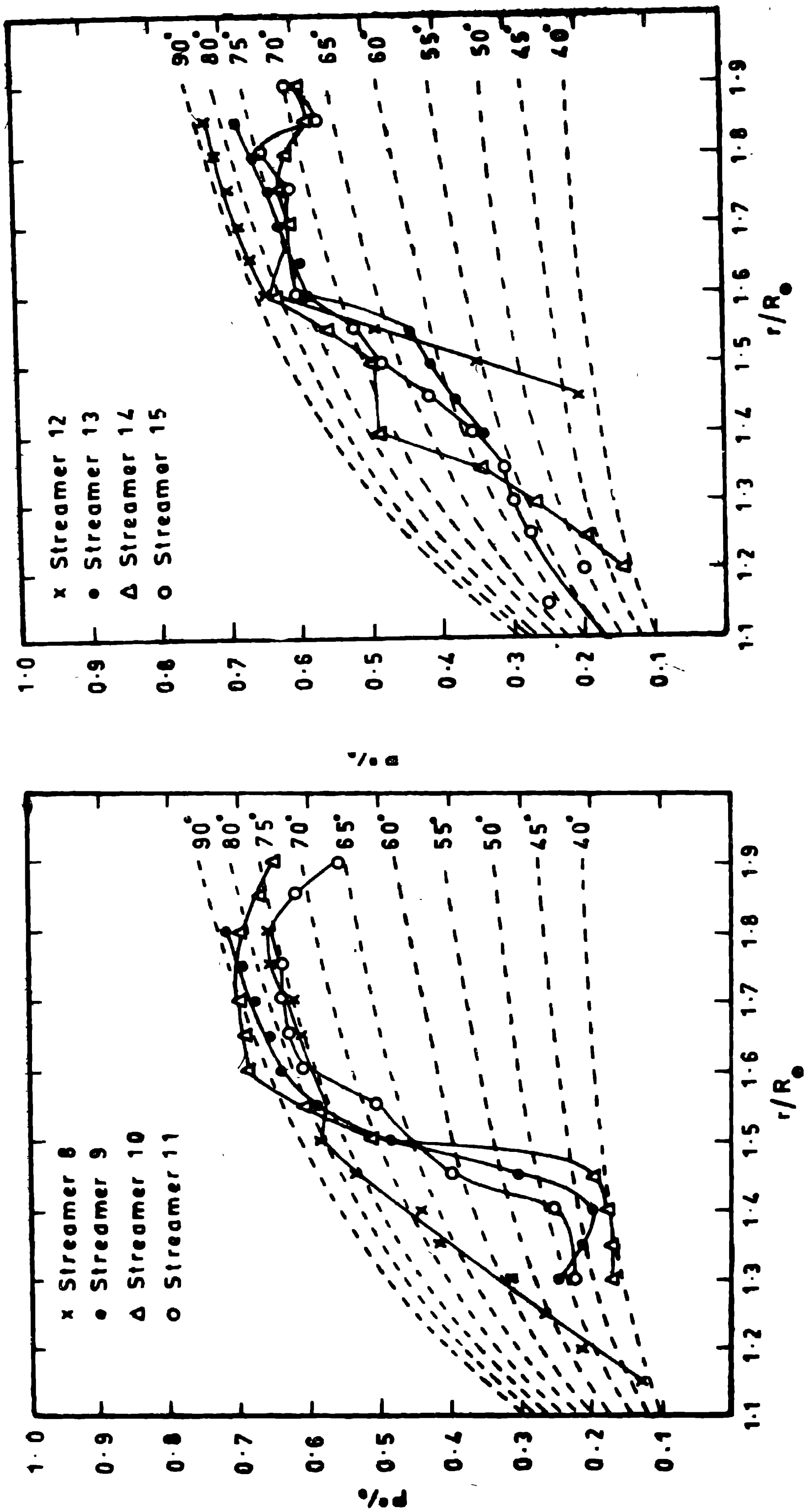

Figure 3. Same as figure 2 for streamers 8 to 15.

Table 1. Polarization of streamer No. 15

$r/R_\odot$	K_{obs}	B	$P_{K,obs}$	P_B	P_S
1.10	100000	50119	0.20	0.21	0.19
1.15	54954	39811	0.25	0.25	0.25
1.20	31623	25119	0.30	0.32	0.22
1.25	11953	14125	0.35	0.38	0.28
1.30	15136	8913	0.39	0.45	0.30
1.35	10965	5623	0.40	0.48	0.32
1.40	7943	3548	0.42	0.48	0.37
1.45	5754	1995	0.44	0.47	0.42
1.50	4169	1259	0.47	0.42	0.49
1.55	3162	794	0.49	0.38	0.53
1.60	2512	398	0.55	0.26	0.60
1.65	1995	200	0.58	0.24	0.62
1.70	1585	79	0.59	0.20	0.61
1.75	1202	32	0.59	0.18	0.60
1.80	955	18	0.62	0.15	0.63
1.85	724	16	0.63	0.13	0.64
1.90	550	14	0.65	0.11	0.66

Table 2. Heliographic coordinates (L and B) of various streamers
($B_0 = -6°.87$, $L_0 = 53°.85$, $P_N = -17°.64$)

Streamer No.	Position angle	θ°	$B°$	$L° - L_0 \pm (L - L_0)$
1	11	76, 52	**55**, 38	**0**, 25
		104, 128	**61**, 49	307, 269
2 P	45	62, 90	20, **27**	357, **327**
		118	27	296
3	70	72	*0*	342
		108	4	306
4	96	75	**−25**	**337**
		105	−21	305
5	118	70	−45	345
		110	**−39**	**291**
6 P	131			
7 P	145	55, 75	−58, −71	27, 351
		125, 105	−45, **−62**	254, **272**
8	200	77	−52	131
		103	**−48**	**171**
9	230	86	**−23**	**142**
		94	−21	151
10 P	244	41, 85	−11, −9	95, 140
		139, 95	0, −8	194, 150
11	255	48, 77	**−3**, 1	**102**, 131
		132, 103	7, 4	186, 156
12	277	87	24	137
		93	**25**	**144**
13 P	290	76	34	121
		104	**38**	**156**
14	303	75	**45**	**114**
		105	51	159
15	318	57, 72	**44**, 55	**83**, 98
		123, 108	55 64	196, 177
16 P	339	55, 72	48, **65**	58, **61**
		125, 108	61, 78	228, 218
17	360	60, 75	49, **62**	78, **92**
		120, 105	62, 71	200, 170

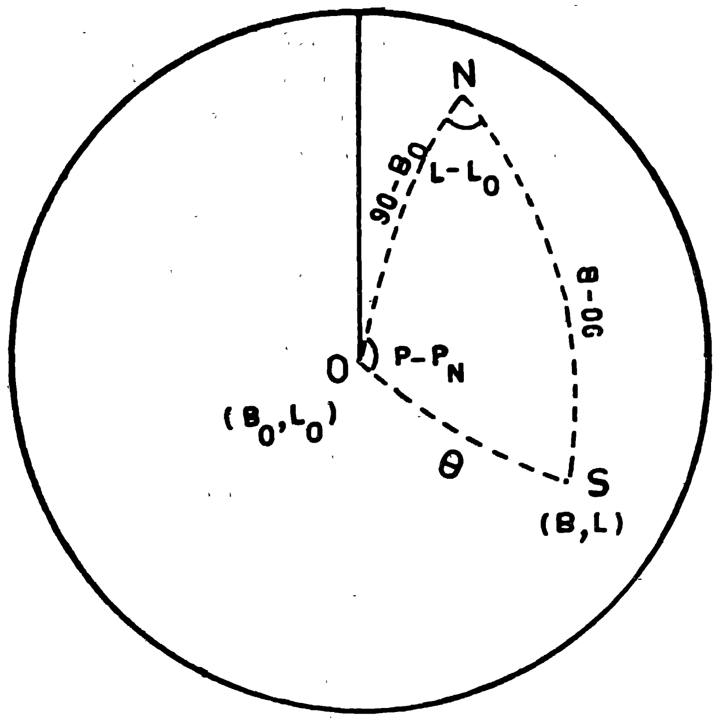

Figure 4. Geometry of the streamer position.

curve, except for streamer No. 6, where no unique value of θ could be assigned because the curve for this streamer was changing very rapidly. The values of θ obtained in this way for each streamer are given in table 2 along with the position angle of that streamer.

From the value of θ, the heliographic coordinates L and B were obtained for each streamer. Figure 4 shows the geometry of the position of the streamer (S) in relation with the centre of the sun (O) and the position angle of the north pole of the sun (N). From the resulting spherical triangle OSN, we get

$$\left.\begin{aligned} \sin B &= \cos\theta \sin B_0 + \sin\theta \cos B_0 \cos (P - P_N) \\ \cos (L - L_0) &= \frac{\cos\theta - \sin B_0 \sin B}{\cos B_0 \cos B} \end{aligned}\right\} \quad \ldots (7)$$

where B_0 and L_0 are the heliographic latitude and longitude of the centre of the sun, P_N is the position angle of the heliographic north pole measured eastward from the north point of the disc and P is the position angle of the streamer. Using the values of P_N, B_0, L_0 for 1980 February 16 and 17 given in the ephemeris, the corresponding values at the time of mid-totality of the eclipse (10^h17^m UT) were obtained as

$$P_N = -17^\circ.64, \quad B_0 = -6^\circ.87, \quad L_0 = 53^\circ.85.$$

Using these values, the heliographic latitude B and longitude L for each streamer was obtained. They are given in table 2.

One disadvantage with this method of determining the orientation of the streamers is that the sign of the angle θ is not known, because of which it cannot be pinpointed whether the streamer originates from behind the plane of the sky or in front of it. Hence for each value of θ, its supplementary angle was also taken and for each streamer two sets of *B* and *L*, one for each hemisphere are given in table 2.

4. Identification of the streamers

As already pointed out, many streamers could not be assigned with a single value of θ and at least two values, one for the lower portion and other for the upper portion of the curve, were needed to completely specify the orientation of the streamer. This may be due to a combination of two independent streamers, one dominating in the lower regions and the other in the outer portions. This is especially true for the streamers on the western limb where any unique value of θ could not be specified in the inner regions. A look at the coronal photograph shows that this region was very active at the time of the eclipse with many streamers intermingling with each other.

As we have noted it is not possible from the polarization data alone to say clearly from which side of the sun the streamer originates. However, careful examination of the solar activity features on the sun, such as spots, plages, *H* filaments etc., on the synoptic solar map at the time of the eclipse may give further information about the origin of the streamer. The synoptic maps observed and compiled by Meudon observatory for Carrington rotations 1691 and 1692 are shown in figures 5 and 6. The part of the solar disc visible at the time of 1980

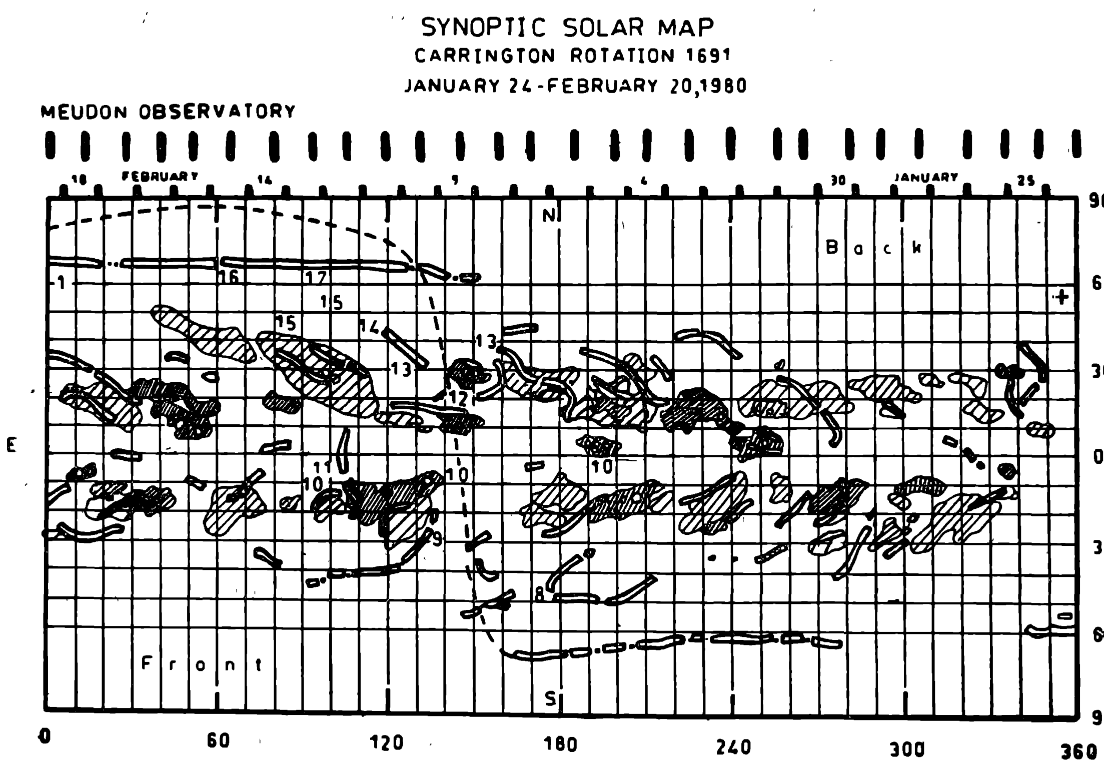

Figure 5. Synoptic solar map for Carrington rotation 1691.

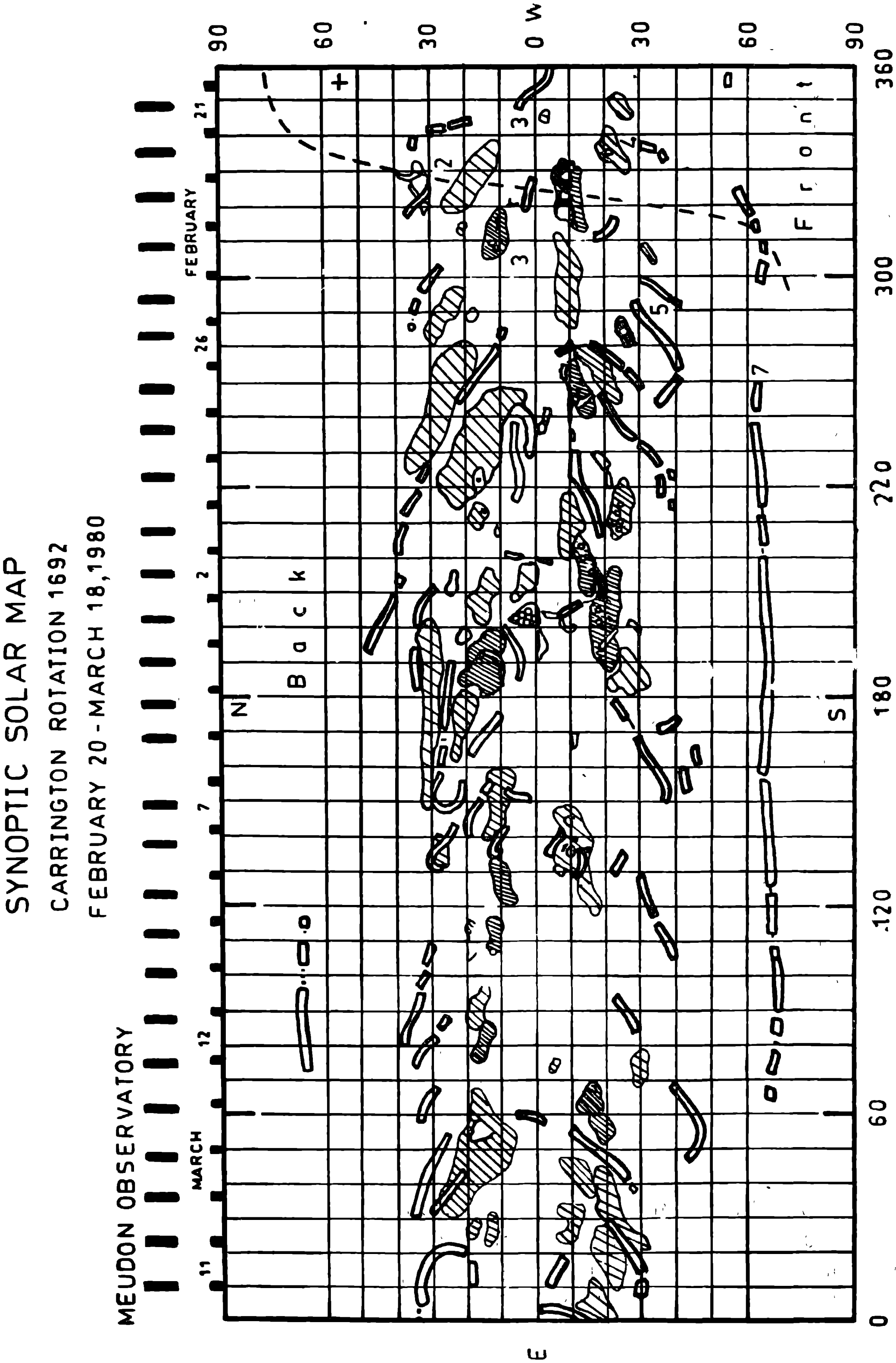

Figure 6. Synoptic solar map for Carrington rotation 1692.

eclipse is the area inside the dotted line. With the help of these synoptic maps the individual streamers were correlated with the active features on the sun's disc as marked in figures 5 and 6 and described below :

Streamer No. 1 : Out of the four possible pairs of values of B and L there is only one set of values $B = 55°$ and $L = 0°$ with $\theta = 76°$ which corresponds to an active region along a filament at $B = 68°$. This shows that it was making an angle of about 14° with the plane of the sky.

Streamer No. 2 : It could be assigned a value of $\theta = 90°$ with $B = 27°$ and $L = 327°$, because there was a prominence near the limb at these coordinates.

Streamer No. 3 : Both pairs of values of B and L for this streamer were associated with either a filament or an active region and both these values seem to be equally probable. Thus selecting any one value of B and L for this streamer is difficult.

Streamer No. 4 : It might be associated with an active region at $B = -25°$ and $L = 337°$, since the other values of B and L did not correspond with any visible feature on the solar disc. Thus this streamer might be originating in front of the disc making an angle of 15° with the plane of the sky.

Streamer No. 5 : It may be associated with an active region at $B = -39°$ and $L = 291°$ behind the disc.

Streamer No. 6 : This streamer could not be assigned any single value of θ. Hence it was difficult to locate its position on the solar disc or its position with respect to the plane of the sky.

Streamer No. 7 : This streamer might be originating from behind the solar disc at $B = 62°$ and $L = 272°$. If this was so, the prominence visible at this position angle at the base of this streamer might not actually be connected with this streamer. The prominence which was actually seen at the limb might be the prominence visible on the synoptic map at $B = -63°$ and $L = 310°$ and this appeared to be at the base of the streamer No. 7 due to the projection on the plane of the sky.

Streamers 8, 9 and 11 : These might be associated with the prominences at $B = -48°, -23°, -3°$ and $L = 172°, 142°, 102°$ respectively.

Streamer No. 10 : This streamer, which was overlying a prominence, could be associated with three out of four possible values of B and L, since all these three positions were connected with some active feature on the disc. But since there was no prominence at the limb at these three positions, it might be that this streamer also, like streamer No. 7, was not actually connected with the prominence which was at its base and it might be only an optical effect.

Streamers No. 12 and 13 : Streamer No. 12 with $B = 25°$, $L = 144°$ might be connected with the prominence at the position angle of 290° on the limb as seen from the synoptic map. On the other hand streamer No. 13, which appears to overlie that prominence, might be coming out from behind the solar disc from a feature at $B = 38°$ and $L = 156°$.

Streamers No. 14 and 15 : Both these streamers might be orginating from the active centres at $B = 45°$, $L = 114°$ and $B = 44°$ and $L = 82°$ respectively, since the other possible values were not associated with any active region on the solar disc.

Streamers No. 16 and 17 : Positions of these streamers seemed to be somewhat preplexing. Out of the four possible values of B and L for each of these streamers, only one set of coordinates for each streamer was connected with a filament and the other possible positions were not associated with any active region. Hence it might be concluded that the streamer no. 16 originated from $B = 65°$ and $L = 62°$ and streamer no. 17 from $B = 62°$ and $L = 92°$. If this was the case, the positions of these two streamers were such that they might be crossing each other since the streamer no. 16 was at position angle 339° and streamer no. 17 at 360° or it might be that one of the streamers (more likely streamer no. 17) was coming from the back of the sun's disc and the other from the front.

Thus almost all the streamers were correlated with the optical features visible on the solar disc. The possible positions of the various streamers are shown with numbers in figures 5 and 6 and the possible coordinates are shown in bold letters in table 2.

5. Discussion

The above analysis was based on the assumption that the streamers were the optical manifestations of the solar activity and hence these were invariably connected to the active features visible on the solar disc. According to Kiepenheuer (1953) there is a close connection between the active centres on the sun and the features in the corona, and the coincidence between the prominences and the coronal streamers are certainly more frequent than random and point to a causal relationship. According to Newkirk (1967) the streamers are the final evolutionary stages of the solar active features. Hence the above assumption was a valid one. Our analysis gives a fairly good correlation between the position of the streamer on the solar disc and the solar active features.

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