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On the formation of a helmet streamer on January 24, 1992 at the south-west limb

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Abstract. We have analysed the soft X-ray images of the sun obtained with the YOHKOH satellite, white light coronal images observed at Mauna Loa and H-alpha pictures of the sun taken at Mitaka and Kodaikanal to study helmet streamers. We find that heating of a filament and subsequent brightening in X-rays, and eruption in the region lead to the formation of the helmet streamer on January 24, 1992. In another event of February 24, 1993, only the brightening and eruption-like expansion of the brightening in soft X-rays lead to the formation of the streamer. No H-alpha filament was seen in this region before and after the event of brightening in soft X-rays and formation of streamer on February 24, 1993. We, therefore, postulate that the plasma in the streamer comes from the solar surface during the X-ray eruption, and magnetic field of the region perhaps helps in containing the plasma and the formation of the streamer.

1. Introduction

Coronal streamers are the enhanced structures in the solar corona extending up to several solar radii. Two types of such streamers have been identified: those situated over active regions and those extending in the corona above prominences or filaments. The use of radial gradient neutral density filters and CCD cameras has made it possible to record the details of streamers and other coronal structures during the occurrence of a total solar eclipse (cf., Koutchmy et al., 1994; Rusin et al., 1997). But even such excellent pictures of the solar corona obtained during the short duration of a total eclipse do not help in the study of the evolution of corona and helmet streamers. This situation has changed with the launch of the YOHKOH spacecraft in 1991 (Tsuneta et al., 1991; Ogawara et al., 1991), which has provided an excellent opportunity to study the dynamics of coronal structures. The soft X-ray telescope (Tsuneta et al., 1991) on YOHKOH produces high-resolution images of the entire sun and inner portion of the solar corona. Images obtained through the Al.1 and Al/Mg filters, used extensively in this study, record most efficiently X-rays from plasma at temperatures greater than 3×10^6 K.

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From an analysis of the eclipse results and assuming a distribution with different degrees of inhomogeneity, Koutchmy et al. (1991) have shown that electron density in coronal streamers is about 5 times higher than the average density in equatorial regions and about 10 times higher in comparison with polar regions. By analysing coronal pictures obtained using the white-light coronagraph aboard SPARTAN 201-01 spacecraft, Guhathakurta and Fisher (1995) found ray-like fine scale structures in streamers similar to those of polar rays. Once we have information about the physical and the morphological characteristics of the streamers, it would be interesting to know the circumstances leading to the formation of these streamers.

The association between prominences / active regions and helmet streamers is well known. The formation and development of prominences can be studied well even while they appear on the solar disc as filaments. But it is not clear at what stage the streamer structure forms. It is very difficult to study the formation of helmet streamers associated with the prominences/ filaments because most of the available data through coronagraphs pertain to the period when filaments/ prominences are close to the limb and by the time one observes the helmet streamer at the solar limb, the streamer structure and the associated prominence are already fully developed. The data that show the formation of helmet streamers found in the literature are scarce. With the availability of soft X-ray pictures of the sun by telescopes on YOHKOH and SOHO, it has become possible to see the streamer structures at the formation stage and investigate the related circumstances. One may ask if the prominences / filaments and helmet streamer structures are formed simultaneously or sequentially. When one observes a streamer structure and a prominence on the east limb, one cannot make out how they were formed because these would have already developed before appearing on the east limb. On the other hand when streamer structure becomes visible on the west limb, one is not sure about the surface activity underlying the streamer structure. Hence, only those streamer structures that develop on a limited portion of the visible disc of the sun, close to the limb, can give clues to their formation. After scanning the SOHO data for about 3 years, we found two such cases.

Using the YOHKOH soft X-ray images, H-alpha pictures and white-light coronal pictures of the sun, Hiei, Hundhausen and Sime (1993) have shown the re-formation of a helmet streamer by magnetic reconnection after the event of a coronal mass ejection in the same region on January 24, 1992. They say that the disappearance of both a large, high-latitude prominence and the overlying coronal helmet streamer seen in pictures obtained by Mauna Loa Solar Observatory (MLSO) on January 22 and 23, strongly implies the occurrence of a prominence eruption and a coronal mass ejection that "blew open" the previously closed magnetic fields. They assume that the re-formation and outward expansion of this streamer was due to reconnection of the magnetic fields opened during the mass ejection event. There is no report of any prominence eruption in this region between January 22-24, 1992. Therefore, we have analysed the additional available data taken around the epoch of this event to investigate the causes for the X-ray brightening and the formation of the helmet streamer. The study of this event became more interesting and complicated because of the existence of another filament almost at the same latitude and separated by about 45 degrees in longitude.

In this paper, we propose a model for the formation of some helmet streamers based on observations in soft X-rays, prominences observed in H-alpha light and white-light images of the corona obtained around the time of X-ray brightening events of January 24, 1992. Although the basic purpose is to report the results of the study of this particular event, we have included another event of formation of a helmet streamer on February 24, 1993, since this event supports the proposed model that the plasma in the streamer comes from the solar surface during X-ray brightening and eruption-like expansion, and magnetic field of the region perhaps helps in containing the plasma and formation of streamers.

2. Observations and results

The copies of full disc X-ray images obtained using Al/Mg and Al.1 filters were made for the period January 22-29, 1992 and February 23-March 1, 1993 to make the measurements of the locations of the X-ray brightenings and X-ray streamers on these days. These positions were compared with the filaments/ prominences observed in H-alpha images of the sun obtained at Mitaka and Kodaikanal observatories during these periods. The H-alpha pictures published in Solar Geophysical Data were also used to fill-in the gap in between the observations made at Mitaka and Kodaikanal. In addition, we compared these structures as seen in soft X-rays with the features seen in the white-light coronal pictures obtained at MLSO. In the following we discuss the physical and dynamical circumstances leading to the formation of two streamers, one on January 24, 1992 and the other on February 24, 1993 on the south-west limb.

3. Event of January 24, 1992

The time evolution of the brightening as observed in soft X-ray pictures of the sun on the south-west limb is shown in Figure 1, covering a period of 3 days beginning on January 24, 1992. The images reveal that there was no coronal activity in the region under consideration at 07:31 UT on January 24. The soft X-ray image obtained at 09:20 UT indicates that the brightening and eruption would have started sometime between 07:30 - 09:20 UT. These cusp-shaped structure increased in intensity and size for about 4 hours. Then the intensity of this structure started decreasing while its size and the extension above the limb continued to increase upto 22:40 UT on January 24, 1992. The details about this event are given in a paper by Hiei, Hundhausen and Sime (1993). It took the shape and structure of a helmet streamer and continued to be visible till January 28. The helmet streamer structure is also seen in white-light images of the solar corona obtained at MLSO during this period. In Table 1 we give the extent of this eruption in position angles and the height of the eruption as a function of data and time. Here the height of the eruption refers to the apparent height of the main intense helmet structure above the limb. The actual height of the streamer may be much larger.

In order to investigate the circumstances leading to the eruption and formation of the helmet streamer, the H-alpha and prominence pictures of the sun obtained at Mitaka and Kodaikanal observatories during the period January 14-25, 1992 were analysed. In Table 2 we list the details of two quiescent filaments, F1 and F2. The development of these H-alpha filaments from January 16-23, 1992 is shown in Figure 2. Figures 3a and 3b show the sketches of H-alpha filaments, prominences and the outline of white-light streamers for the period January 16-28, 1992. We have outlined only the bright part of the streamers marked as S whereas the faint part

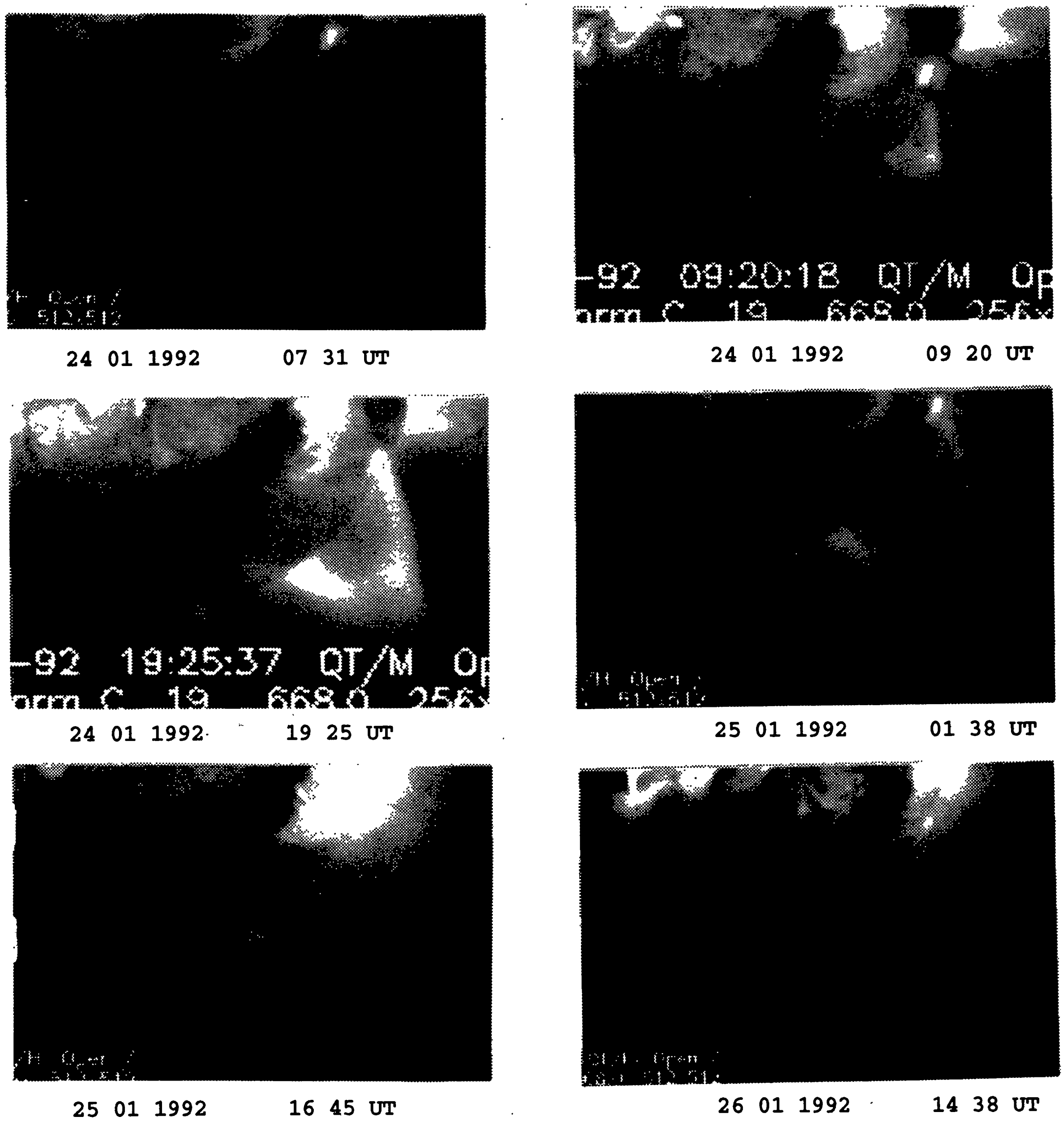

Figure 1. Developmental of eruption, brightening and formation of a helmet streamer structure as seen in the YOHKOH soft X-ray images on January 24, 1992. Date and time are indicated below each image.

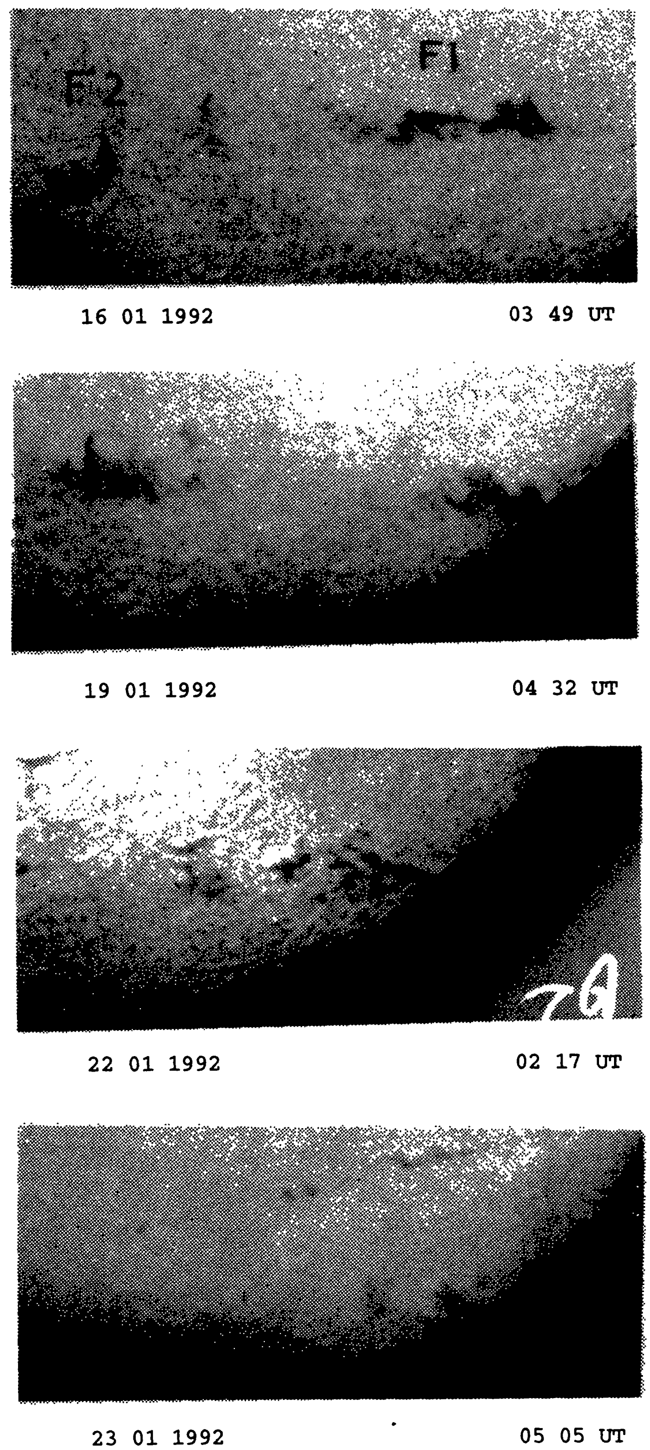

Figure 2. H-alpha images of the portion of the sun taken during January 16-23, 1992 show the weakening of the H-alpha filament near the south-west limb connected with this event. Filaments F1 and F2 have been marked in the image of January 16. The image of January 22 shows the prominence connected with filament F1. Date and time of observations are given below each image.

extends to much larger distances in the solar corona. The gap between the marking of the solar limb and the streamer is due to the occulting disc of the coronagraph. The two quiescent filaments have been marked as F1 and F2. The filled regions at the limb indicate the prominences as observed in H-alpha. Figure 3b shows only white light streamer structures as there were no filaments and prominences in this region of the sun after January 26.

The filament F1 reached the west limb on January 18 and a large bright helmet streamer was seen in the coronal picture taken at MLSO on the same day, at the west limb at a mean position angle of about 242 degree. This streamer must be associated with the filament F1 and may not be related with the filament F2 which was seen on the disc near the central meridian (about 3 degree west) at that time. The coronal pictures on subsequent days show that the streamer structure moved slowly towards south and reached at a mean position angle of about 230 degree on January 23, and reduced in size, extent and intensity. The apparent shift in position of the streamer may be due to the fact that the eastern portion of the filament is at a higher latitude as seen in the H-alpha picture of January 18.

The H-alpha images taken during January 20-23 show a prominence at the south-west limb underlying the helmet streamer structure. This prominence is associated with the filament F1. The H-alpha images of January 22 and 23 indicate that the filament F2 was in a state of diffusion and expansion at the disc near the south-west limb. Here we use the term diffusion since the H-alpha filament was getting less dark and larger in extent. These filaments did not

Table 1. Details of the helmet streamer as seen in soft X-ray images

Date	Time in UT	Extent of eruption in degrees	Height of eruption from limb (solar radius)
24 01 92	07 31 28	No large activity seen	
24 01 92	09 20 18	224 - 238	0.13
24 01 92	09 45 54	215 - 238	0.14
24 01 92	10 33 05	217 - 240	0.21
24 01 92	11 22 41	218 - 240	0.22
24 01 92	12 46 57	217 - 242	0.28
24 01 92	19 25 37	212 - 244	0.39
24 01 92	22 40 59	211 - 244	0.53
25 01 92	01 38 37	210 - 245	0.60
25 01 92	11 56 49	210 - 241	0.62
25 01 92	16 45 03	208 - 239	0.67
26 01 92	14 39 13	203 - 238	0.47
27 01 92	02 16 47	205 - 237	--
28 01 92	00 57 53	194 - 230	--
29 01 92	03 21 07	--	--

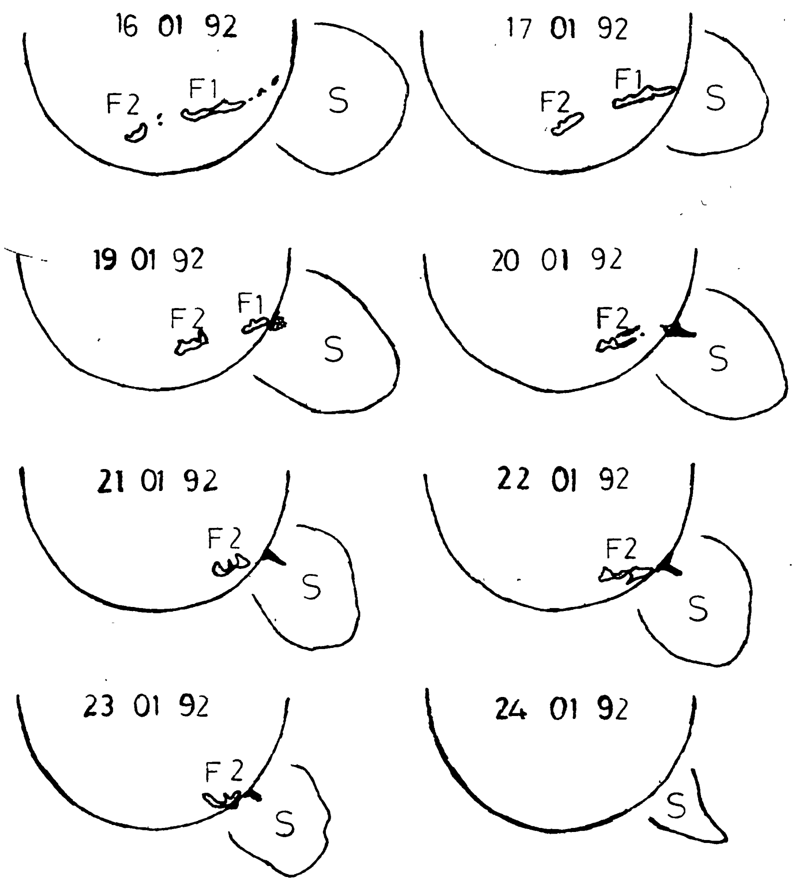

Figure 3a. Sketches of H-alpha filaments F1 and F2, prominences (filled portion at the south-west limb) and the white-light coronal streamer marked by S as a function of time. The gap between the solar limb and streamer is due to the occulting disc of the coronagraph.

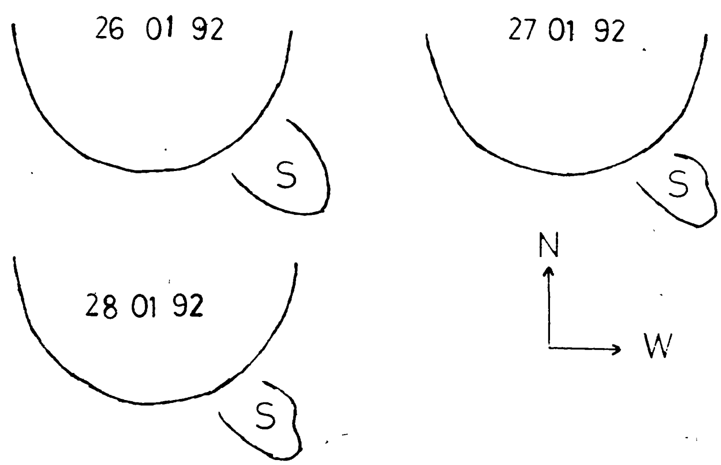

Figure 3b. Sketches of white-light streamer associated with the X-ray brightening event of January 24, 1992 as a function of time. There were no filaments and prominences seen in this region.

disappear when seen on the disc and no eruption of prominences associated with these filaments has been observed and reported. These two filaments were at two different locations separated by a small difference in latitude. It is difficult to make out the separation on smaller images. Further, the soft X-ray picture of January 22 shows a loop structure on the south-west limb (Figure 4) and the inner bright loop structure appears centered around the location of the H-alpha prominence on that day, confirming the association between the filament F1, the related prominence and the helmet streamer seen in coronal images obtained at MLSO during January 16-23, 1992. The quiescent prominence on the west limb and associated white light helmet streamer could be seen for a long duration (January 16-23) due to the large extent of the filament F1 in the east-west direction. The helmet streamer that formed on January 24 continued to be visible till January 28 on the west limb. Hiei, Hundhausen and Sime (1993) have proposed that the prominence and overlaying coronal streamer disappeared after the opening of the closed magnetic fields, and the helmet streamer was re-formed by the reconnection of magnetic

Table 2. Details of H-alpha filament

Date	Time in UT	Lat. Extent (Degrees)	Long. Extent (Degrees)
Filament F1			
14 01 92	15 20	35 - 40 S	13E - 15W
15 01 92	03 42	33 - 40 S	04E - 22W
16 01 92	02 53	31 - 38 S	08W - 38W
17 01 92	05 48	32 - 38 S	22W - 60W
18 01 92	02 40	33 - 40 S	35W- limb
19 01 92	04 32	35 - 42 S	46W - limb
20 01 92	02 54	A small filament and prominence on west limb	
22 01 92	02 17	Prominence visible	
Filament F2			
17 01 92	05 48	38 - 45 S	16E - 05E
18 01 92	02 40	40 - 50 S	05E - 11W
19 01 92	04 32	40 - 49 S	04W - 23W
20 01 92	02 54	41 - 50 S	12W - 28W
21 01 92	05 27	41 - 51 S	26W - 49W
22 01 92	02 17	41 - 52 S	35W - 75W
22 01 92	04 39	42 - 52 S	36W - 75W
22 01 92	06 20	42 - 53 S	37W - 74W
23 01 92	05 05	46 - 60 S	46W - limb
23 01 92	15 17	A small portion at west limb	
24 01 92	04 17	-	-

fields opened by the mass ejection. This implies that the same helmet streamer was visible on the west limb for about 12 days from January 16-28, 1992, which appears impossible considering the solar rotation. One generally sees the same helmet streamer on the solar limb for about 5-6 days. From all these observations it appears that the helmet streamer seen in the coronal images on the south-west limb during January 16-23, 1992 was associated with the filament F1, and the one seen during January 24-28 was associated with the filament F2.

The H-alpha image on January 22 shows the filament F2 to be less dark, which is conspicuous in the image of January 23 at 05:05 UT. It appears that this filament has risen more above the solar surface and became weaker in H-alpha on January 23. An H-alpha image about 13 hours later shows a very small portion of this filament in this region and a faint prominence north of this filament, associated with the filament F1. The filament F2 seen in H-alpha on January 23 at 05:05 UT was very faint at a high latitude of 46-60° south, compared with its average latitude of 40-50 degree. The reason for this may be the increase in the height of the filament above the solar surface. The filament did not disappear when it was on the disc and no prominence associated with this filament was seen at the west limb. Also no prominence eruption in this region was seen. From the less dark and expanded nature of the filament, we assume that the plasma in the filament was heated up through some physical process. The heating of plasma caused the filament to rise above the solar surface and to appear less dark in H-alpha images of the sun. This can also explain the non-visibility of this filament as a prominence on January 24 and 25 on the south-west limb at the position angle of about 225 degree. These observations have been confirmed by the published data in the Solar-Geophysical Data Prompt Reports (1992). The above discussion agrees well with the findings of Singh and Gupta (1995) that a filament becomes less dark and partly invisible in H-alpha pictures about 1-2 days prior to its disappearance and they explained it in terms of heating of plasma in the filament.

Generally the word "eruption" is linked with prominence eruption. But no associated prominence eruption was seen before or during the event of soft X-ray brightening at the south-west limb on January 24, 1992. We have referred this brightening in soft X-rays, which expanded in the form of cusp-shaped loops, as eruption in soft X-rays. In the absence of any disappearance of a filament or prominence eruption, it is less likely that magnetic fields opened up and then reconnected to re-form the helmet streamer as reported by Hiei, Hundhausen and Sime (1993).

We have monitored the sun in H-alpha continuously using a spectroheliоscope at Kodiakanal Observatory during January 21-25, 1992 and seen the reports of other observatories on prominence eruption. We did not observe any prominence eruptiion on the west limb in the region under investigation, during this period. We suggest that the brightening and subsequent eruption in the active region corona in X-rays discussed above was probably triggered by the heating of plasma in the filament, without the occurrence of filament disappearance or prominence eruption. Most likely the plasma in the helmet streamer came from the solar surface during the brightening in soft X-rays and eruption-like expansion phase and perhaps it was contained by the cusp-shaped magnetic field in the region, rather than it was due to inflow associated with a magnetic reconnection process. Now, we discuss another event of streamer formation on February 24, 1993, which supports the above arguments.

4. Event of February 24, 1993

In Figure 5 we show the brightening, eruption in soft X-rays and the development of a streamer in the south-west quadrant as observed in the soft X-ray pictures of the sun obtained by YOHKOH during February 24 March 1, 1993. The data and time of observation are given below each picture. The images indicate that the beginning of eruption and brightening in soft X-rays occurred around 17:39 UT on February 24. The brightening grew in size and extended over 46-59 S in latitude and 32-58 E in longitude around 19:16 UT. The brightening occurred in the form of arches. The subsequent pictures show the rapid increase in intensity, increase in the number of arches and rise in the middle portion of arches above the solar surface. The soft X-ray picture obtained at 11:48 UT on February 25 depicts the formation of a streamer. The coronal pictures for the period February 23 - March 1, 1993 obtained at MLSO also show the formation of a white light streamer on February 25 coinciding with the one observed in soft X-rays on February 25 and subsequent days.

Figure 4. Soft X-ray image of January 22,1992. This shows the loop structure on the south-west limb coinciding with the MLSO coronal streamer. The brightening inside the loop is centered around the H- alpha prominence on that day.

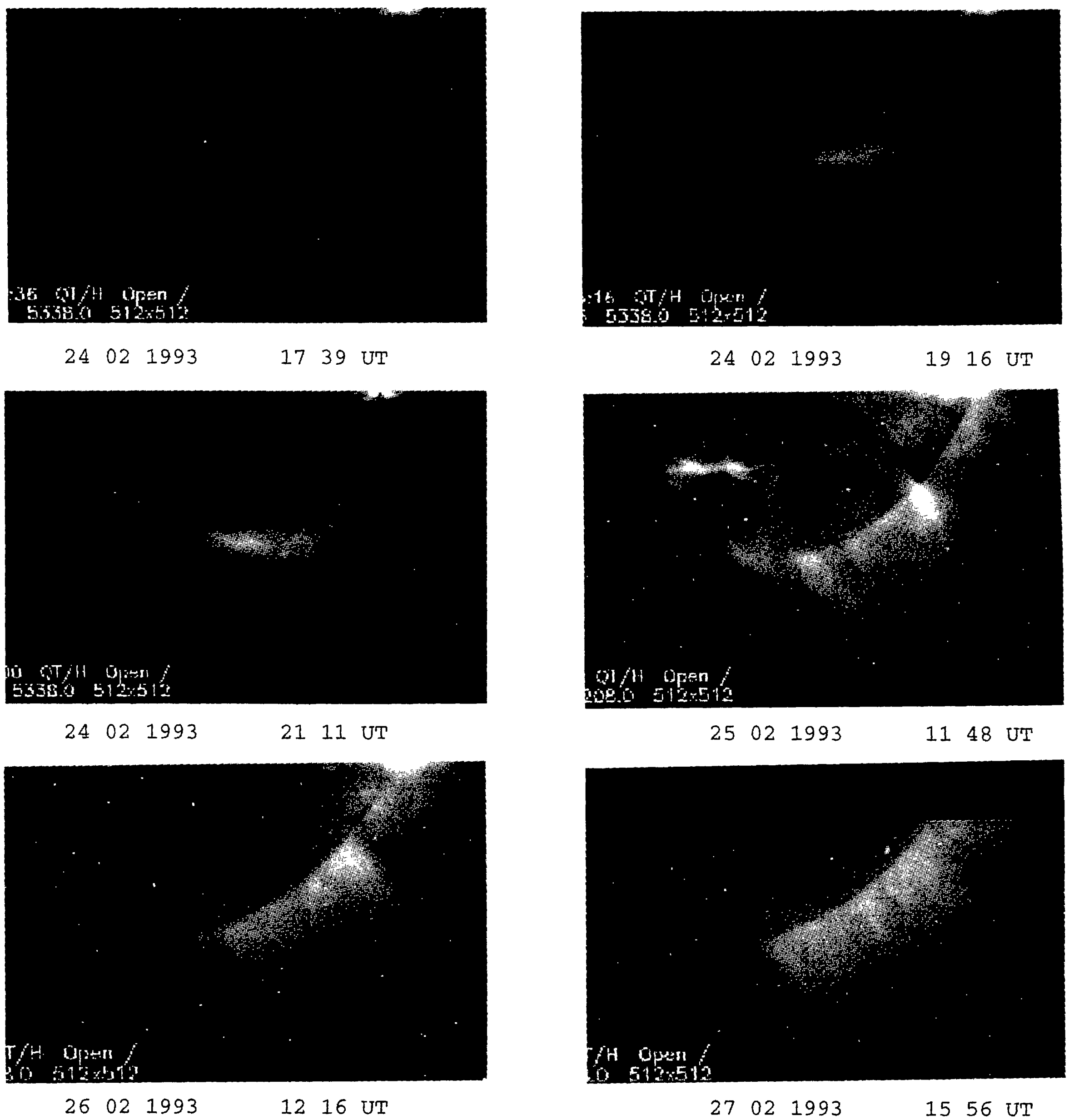

Figure 5. Development of eruption, brightening and formation of a streamer structure as seen in the YOHKOH Soft X-ray images on February 24, 1993. Date and time of observations are indicated below each image.

To investigate the circumstances which lead to the formation of this streamer, we have examined the H-alpha pictures of the sun obtained at Mitaka and Kodaikanal observatories and those published in Solar-Geophysical Data Prompt Reports for the period February 20-25, 1993. None of the quiescent or active filaments seen on the solar disc lie in the location of the observed enhancement and helmet streamer. The region was void of sunspots and other solar activity before the sudden eruption and brightening on February 24. Thus the streamer was formed in the absence of any H-alpha filament and large-scale magnetic activity in the region. Only the brightening and eruption in soft X-rays lead to the formation of the streamer, consistent with the suggestion that the plasma in the helmet streamer came from the solar surface, rather than from an inflow associated with a magnetic reconnection process.

5 Discussions

There can be a number of possibilities about the formation of helmet streamers. First possibility is by the reconnection of magnetic lines as proposed by Hiei, Hundhausen and Sime(1993). In their model a filament erupted causing the opening of closed magnetic fields and then reconnection of magnetic fields opened by the coronal mass ejection event caused the re-formation and outward expansion of the streamer. In this model the streamer structure existed earlier and it re-formed again after the event of X-ray brightening. But it is difficult to observe the same streamer structure for 10-12 days on a limb due to solar rotation. The question then arises: if the helmet streamer existed earlier, how and when was it formed?

The second possibility is that a quiescent filament forms along the neutral line with the development of magnetic field in the region, and a helmet streamer overlying the quiescent prominence. In this scenario, it is not clear how the enhancement of plasma density or inflow of plasma in the streamer structure occurs. It is also possible that a prominence form earlier and when it erupts, the helmet streamer forms due to reconnection of magnetic fields. In this picture only one feature, either a prominence or a helmet streamer, should be seen at a time. But most of the observations indicate that both features are associated and co-exist for some time.

In another method, a magnetic field develops in a region which may or may not lead to the formation of an H-alpha filament. If the plasma supported by magnetic field along the neutral line is cooler, it may be seen as an H-alpha filament. On the other hand if the plasma gets hotter say to a temperature $> 10^4$ K it may not be clearly visible as an H-alpha filament or a prominence. The heated plasma at a moderate temperature (not at coronal temperature) may trigger some physical process, causing brightening in soft X-rays and plasma at coronal temperatures of 2-3 x 10^6 K. It is not possible to comment on the type of physical process involved in triggering of soft X-ray brightening at this stage.

We have investigated two cases in which brightening in soft X-rays led to the formation of streamer structures. In the first case of the formation of helmet streamer on Janurary 24, 1992 we found that a filament was visible on the solar disc on Jan. 17, which reached the west limb on Jan. 23. The filament appeared to have become fainter and risen above the solar surface as seen in the bottom panel of Figure 2. The cause of this effect may be the heating of plasma in the filament to a temperature of the order of 10^4 K. In the second case, no H-alpha filament was seen before the brightening in soft X-rays and streamer formation. This is the only difference between the two cases.

Recent magnetic observations from SOHO have indicated the presence of magnetic fields everywhere like a carpet. The emergence and alignment of magnetic fields do create positive or negative polarity dominated regions and neutral regions where filaments may form. From the limited available data on the formation of streamer structures it is difficult to pin point the exact physical circumstances. From the observations it appears that initially plasma is heated to a temperature of the order of 10^4 K and then the heated plasma triggers some physical process responsible for the brightening in soft X-rays and formation of streamer structures. During the expansion of a soft X-ray brightening the heated plasma at coronal temperature moves up from the solar surface, which may be contained by the magnetic field in the region in the form of a streamer structure. In this process a realignment of magnetic fields also may occur.

6. Summary

To summarise the results we may say that at least some helmet streamers are formed after brightening and eruption in soft X-rays in the region of a quiescent filament or non-filament region and the plasma in the streamer comes from the solar surface due to some heating process. Magnetic field in the region perhaps helps in containing the plasma in the streamer. We need coordinated data in multi-wavelengths and at frequent intervals to delineate the role of various physical processes which contribute to the formation of streamers.

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