Chapter 6

DYNAMICS OF FLARING ARCHES

6.1 Introduction

Solar flares are considered to consist of various components which include loops, ribbons, arches, surges and erupting filaments. Martin (1989) has classified these components into two separate classes viz. coronal flare components comprising of flare loops, flaring arches, erupting filaments and expanding coronal features while the chromospheric flare components consist of flare ribbons and remote patches.

The coronal flare components have parts or phases that include very high temperatures (invisible in Hα) as well as relatively low temperatures (visible in Hα). The term flaring arches was first introduced by Mouradian et al. (1983) to refer to a component of flare which was not discussed earlier. Flaring arches are now more specifically defined as a component in which emitting mass is observed to flow upward into the corona, traverse an arch like path and descend to another distant point in the chromosphere. Flaring arches can vary over a wide range of dimensions and intensities.
at the observed wavelengths. In case of a flaring arch, the primary footpoint is located within a chromospheric flare or a subflare and the remote secondary footpoint is basically passive. Energy seems to be released at the primary footpoint and its effect propagates along the arch towards the secondary footpoint. The secondary footpoint is thousands of kilometers away from the source flare but in the same active region or in the quiet region chromosphere surrounding the active region. It brightens in $H\alpha$ concurrent with the beginning of hard X-ray burst at the primary site.

Since the flaring arches are very rarely mentioned events, Bruzek (1967) misidentified the flaring arches as an arch filament system. Rust et al. (1985) had also studied two similar flaring arches. Fontenla et al. (1989) studied flaring arches phenomena in UV lines. Martin and Švestka (1988) described the flaring arches as a mechanism for the release of energy in the lower corona. They discussed four distinct phases of flaring arches phenomena observed from BBSO from Nov 6-13, 1980 and with the Hard X-ray Imaging Spectrometer (HXIS) onboard the Solar Maximum Mission (SMM). A comparative study of $H\alpha$, OV and X-ray data for a flaring arch event has been made by Švestka et al. (1989).

### 6.2 Flaring arches

Both the X-ray and $H\alpha$ emissions appear to flow into the corona from a primary footpoint in a flare with the X-ray component preceding the $H\alpha$ flow. The secondary footpoint brightens in $H\alpha$ within seconds after the onset of the flare associated hard X-ray burst while the X-ray brightening at this footpoint is more delayed (Martin and Švestka 1988). But the maxima of brightness at the secondary footpoint occurs at the same time both in $H\alpha$ and X-rays. They described the four phases of flaring
arch as follows.

1. An early phase in which secondary footpoint brightens in H\(_\alpha\) due to propagation of energetic electrons through the arch.

2. A second phase characterized by X-ray emission propagating through the arch, accompanied by further brightening of the secondary footpoint in H\(_\alpha\) and X-rays.

3. A third phase in which the H\(_\alpha\) material flows through the arch but with no additional brightening of the secondary footpoint.

4. A fourth phase where low intensity H\(_\alpha\) emitting mass is seen to propagate in the reverse direction through the arch, sometimes associated with a new weak X-ray brightening.

Speeds of propagation derived from the X-ray and H\(_\alpha\) components suggest that the propagation of the various components through the arch follows the temperature pattern. Highest speeds are observed at the initial stage; intermediate speeds (400-1900 km s\(^{-1}\)) and low speeds (less than 400 km s\(^{-1}\)) observed later, are characteristic of H\(_\alpha\) phase. Svestka et al. (1989) from their comparative study of H\(_\alpha\), OV and X-ray data for the flaring arch show that

1. there exists a hot conduction front producing X-rays in the least dense plasma ahead of a decelerating more dense plasma bulk seen next in OV and still more decelerating dense plasma in H\(_\alpha\) observed later,

2. there is a gradient in density from the primary towards the secondary footpoint by a factor of 3 in X-rays, one order of magnitude in OV and probably more in
the densest loops which emit in Hα.

3. the secondary footprint with hard X-ray spectrum is mainly excited by particle streams.

The above mentioned conclusions by several authors are based on observational evidences. However, the mass ejection into the flaring arches and X-ray emission along the arches need theoretical modelling.

6.3 Objective

In order to have a better understanding of this newly classified component of solar flares, a detailed temporal and morphological study of the flaring arches and the associated eruptive flares observed from Udaipur Solar Observatory has been made. An attempt has been made to understand the physical processes involved in flaring arches.

6.4 Observations

We have observed three flaring arch events during March 5-7, 1991 using the high resolution solar spar telescope at USO. These homologous flaring arches and eruptive flares occurred in an observationally favourable location near the south-east limb in the active region (Arl) Boulder No. 6538. The AR 6538 emerged at the SE limb on March 4, 1991.

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6.4.1 March 5, 1991

Surge activity was seen at the SE limb on March 4, 1991 indicating the arrival of AR 6538. On March 5/05:00:00 UT an intense and rapid small surge activity occurred prior to 5:30:00 UT, when an intense rapidly ascending mass, marked as “A”, appeared in this region. This assumed the shape of a twisted huge flaring arch connecting it to a footpoint behind the limb (Figure 6.1 - 06:40:48 UT). The arch system reached a maximum height of 110,000 km from the limb with a maximum speed of 400 km s$^{-1}$ as depicted in Figure 6.2, wherein the temporal evolution of the height of the flaring arch is shown. It is noticed that much before the primary leg “A” of the arch connected to the secondary footpoint marked “B” behind the limb, a conspicuous increase in brightness occurred above the limb at several places around “B” (Figure 6.1 - 06:40:48 UT). The time delay between H$\alpha$ mass reaching “B” and the footpoint brightening is observed to be 15 minutes. Two hours later, another very bright mass ejection ensued from the primary footpoint location (cf. Figure 6.1b). Contrary to the preceding case of flaring arch where material was seen moving along the arch from the primary to the secondary footpoints, the mass ejection in this eruptive flare occurred almost vertically, with a maximum speed of 110 km s$^{-1}$. The ejected mass reached a height of 60,000 km and then descended with a speed of about 50 km s$^{-1}$ along the same path (cf. Figure 6.3). The material and density of the material involved in the eruptive flare appeared to be several times more than in case of flaring arch.
Homologous flaring arch and eruptive flare observed on E-limb on March 5, 1991.
6.4.2 March 6, 1991.

On March 6, 1991 in the same active region No 6538, at 10:40:00 UT, another set of flaring arches originated. Marked brightening was observed again at several points near the secondary footpoint marked "B" (Figure 6.1c - 11:00:59 UT) even before the arches connected to the secondary footpoints, as observed in the case of March 5, 1991 event. The time-delay between the two was again approximately 15 minutes. The \( \text{H}_\alpha \) material in this event travelled an arch 163,300 km long with a maximum speed of 140 km s\(^{-1}\) attaining a height of 52,000 km. The descending speed of the two \( \text{H}_\alpha \) knots along the arch was found to be 97 km s\(^{-1}\) and 60 km s\(^{-1}\). The variation of height of the arch with time is shown in Figure 6.4. The duration of this event was about 45 minutes beyond which observations at USO discontinued due to sunset. Therefore, it is not certain if an eruptive flare ensued after the flaring arch event.
Figure 6.3: Variation of height of the eruptive flare observed after flaring arch event on March 5, 1991 with time. Here, a and b are two different HIa knots.

Figure 6.4: Variation of height with time for two features a and b, in the flaring arch event observed on March 6, 1991.
6.4.3 March 7, 1991

In succession of the events of March 5 and 6, flaring arches ensued again in the same active region no. 6538 on March 7. By this time, the active region had rotated off the east limb, hence identification of the flaring arch footpoints could be made (Figure 5a - 06:59:47 - 07:45:50 UT). In this case, the flaring arch was observed to originate from the top of a pre-existing dense, low-lying bright loop "A" (07:06:54 UT frame) at the location S20E66 which then bent towards a bright plage region "B" near the east limb, slightly away from the primary footpoint. This plage "B" brightened about 20 minutes before the flaring arch was even visible at the footpoint "A". In Figure 6.6, is given the height versus the time plot of this event, indicating that the flaring arch rose with an average speed of 85 km s$^{-1}$ traversing an arch of 250,000 km length and reaching to a maximum height of 80,000 km. From the high resolution pictures of the active region taken on March 9, 1991, it is confirmed that the flaring arch terminated on to an emerging flux region. Before the flaring arch completely subsided, another highly energetic and rapid mass ejection commenced at 07:47:10 UT from the top of the same low-lying dense bright loop "A" at "E" (Figure 6.7 - 07:47:36 UT). Its location was only 20 arc-seconds away from the primary footpoint of the flaring arch. This eruptive flare was most energetic as II$\alpha$ blobs were found to move vertically upward with an initial speed of 500 km s$^{-1}$ and then attaining a maximum speed $\approx$ 1200 km s$^{-1}$ (cf. Figure 6.8).
Figure 6.5: Homologous flaring arch and eruptive flare of March 7, 1991. A is the primary footpoint shown in the form of bright plage loop and B is the secondary footpoint.
Figure 6.6: The Active region on March 9, 1991

From the movie made at USO, of this event, it was observed that plasma blobs were shot out at short intervals with enormous acceleration, maximum being 565 km s$^{-2}$ for the blob 3 as seen in Figure 6.7. The ejected material reached a maximum height of more than 350,000 km where its density decreased and became too diffuse to be discernable. It may be noted that these energetic events failed to affect the stability of a neighbouring curvilinear filament f (cf. Figure 6.5). A comparative table for the three flaring arch events are given in Table 6.1. Table 6.2 shows comparison of eruptive flares in the same region.
Figure 6.7: Height versus time plot for two $H_\alpha$ knots in case of flaring arch of March 7, 1991 event.

Figure 6.8: Height versus time plot for three knots of the eruptive flare followed by the flaring arch event on March 7, 1991.
Table 6.1:

**FLARING ARCHES: MARCH 5-7 1991**

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Date</th>
<th>Length (km)</th>
<th>Height (km)</th>
<th>Ascending speed (km s(^{-1}))</th>
<th>Descending speed (km s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>March 5 1991</td>
<td>345000</td>
<td>110000</td>
<td>106</td>
<td>56</td>
</tr>
<tr>
<td>2.</td>
<td>March 6 1991</td>
<td>163300</td>
<td>52000</td>
<td>120 -142</td>
<td>60 -100</td>
</tr>
<tr>
<td>3.</td>
<td>March 7 1991</td>
<td>251000</td>
<td>80000</td>
<td>82</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 6.2:

**ERUPTIVE FLARES: MARCH 5 & 6 1991**

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Date</th>
<th>Length (km)</th>
<th>Height (km)</th>
<th>Ascending speed (km s(^{-1}))</th>
<th>Descending speed (km s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>March 5, 1991</td>
<td>190000</td>
<td>62000</td>
<td>100</td>
<td>65</td>
</tr>
<tr>
<td>2.</td>
<td>March 7, 1991</td>
<td>350000</td>
<td>350000</td>
<td>1200</td>
<td>-</td>
</tr>
</tbody>
</table>

6.5 Results

The shapes and sizes of the three flaring arches observed during March 5-7, 1991 were remarkably similar. The similarity of the events suggest that repetitive restoration of the local magnetic field conditions and build up of sufficient energy could occur within a day. The observed time delay of 15-20 minutes between the emergence of the flaring arches and the brightening of the secondary footpoint is perhaps due to the heating by particle bombardment of the chromosphere as explained in the case
of giant X-ray arches first discovered by Švestka et al. (1982). Martin and Švestka (1988) suggested that the flaring arches possess an X-ray phase which precedes \( \text{H}_\alpha \) emission and hence the secondary footpoint brightens up much before the \( \text{H}_\alpha \) mass reaches to the secondary from the primary footpoint.

In both the events of March 5 and 7, flaring arches were followed by very energetic eruptive flares. The question arises as to what is the source for large amount of material that is supplied in the arches and eruptive flares? It is to be noticed that at the site of the flaring arches and eruptive flares, no large scale plage or filament were seen except for a small, dense, low-lying emission loop. It does not appear probable that such a small “plage loop” could have provided the enormous material involved in the observed flaring arches and eruptive flares. It is more likely that a sudden interaction between small flare-loops (plage loop) and extended loops (flaring arch) took place which initiated a “siphoning process” by suitably modifying or opening up the magnetic field structure through reconnection of magnetic field lines, so that the fast mass ejection could take place. The observational evidence for the above suggestion is ensuing of a needle-like emission from this the top of the plage loop into the corona. The plage loop in this case could be considered here as flare loops while the flaring arches are ejection of material along pre-existing magnetic field lines, adjacent to those directly involved in the reconnection process. This is a distinct case of reconnection process of field lines coming closer and releasing the energy (cf. Figure 6.9) However, the homologous flaring arch activity suggests that the magnetic field configuration somehow restores itself within a day to its original configuration. Theoretical modelling of various observed phenomena related to the homologous flaring arches and eruptive flares are required to confirm these suggestions.
6.6 Conclusion

From the comparative, temporal study of flaring arches and eruptive flares followed by it in active region, it is concluded that the two are entirely different phenomena. In case of flaring arch, material is seen to be ejected along the pre-existing field lines. The material does not erupt into the corona but falls back to the chromosphere. This resembles a bright surge rather than an erupting filament. The eruptive flare however is a different phenomena which involves the activation of highly stressed fields rooted close to polarity inversion lines. Theoretical modelling of various observed phenomena related to the homologous flaring arches and eruptive flares are required to settle these questions.