CHAPTER III

OBSERVATIONS AND ANALYSIS OF H-ALPHA TWO RIBBON FLARES

1. INTRODUCTION AND OBJECTIVE

In this chapter, I have described high resolution H-alpha observations of 30 Two-Ribbon flares, to study the location of flare ribbons relative to sunspot groups, separation of flare ribbons and expansion of flare loops in active region. This study is made to obtain the following objectives:

1) Orientation of flare kernels forming the flare ribbons with respect to sunspot groups and their magnetic polarity, pre-flare plage and fibril location.

2) Whether all flare kernels those form two flare ribbons show movement (or some of them remain stationary) and if all kernels show movement, move with the same speed as the kernels in opposite ribbon.

3) Whether the pattern of growth curve of kernels in opposite flare ribbons is similar or not.

4) To study the growth of the flare loops.

5) To determine the H-alpha energy in different importance class Two-Ribbon flares and to compare with H-alpha energy in non-two ribbon flares.
The study of H-alpha two ribbon flares is made in three different parts; according to characteristic of region. The regions which produce two-ribbon (TR) flares may be divided in three parts - namely - I - Spotless regions, II - Single spot regions, and III - Complex regions with many spots. Given in this section are, variation in plage area, position of filament (if exist) and its motion and growth and decay of fibrils before, during and after the flare. For this purpose, I have described 11 events for which almost complete data on the flares are available.

2.1 Spotless regions

It has been established that the flare nodules first form on both sides of the zero line of the longitudinal magnetic field and then extend along the zero line. The TR-flares in old spotless regions or regions with small spots always appear associated with existing filament. The most typical case is a flare that forms at a place where a filament had disappeared immediately before. According to Dodson and Hedeman (1970) essentially all large flares in old active regions develop in this way (following the disappearance of dark filament).
Out of 9 events of TR flares occurred in spotless regions, 4 events described in relation to plage, filament and magnetic field configuration. The list of events is given in Table III-1.

2.1.1 Flare of 17 May 1980

The H-alpha observations were made of Hale regions No.16852 and 16853, both regions were spotless and were part the region 16787. The H-alpha observations on May 17, 1980 of this region (N 20 E 45) showed a curvilinear filament F as shown in figure III-1 (a). Around 0324 UT the N-E plage appeared brighter as compared to opposite S-E side of the filament F. Around 0743 UT, a new arc shape filament F1 appeared as shown in figure III-1 (b). The plages became brighter, before the occurrence of the TR-flare. The filament F and F1 both showed motion. The filament F1 seen as absorbing feature in H-alpha line center and upto H_α -0.3Å° (violet), appeared as bright surge in H_α -0.5Å°, but was not observed at all at H_α -1.0Å°. On the other hand in the case of filament F; the west portion appeared diffusing and N-E portion was darkening upto H_α -0.5Å°. In H_α -1.0Å° only faint top NE portion of F was observed. The off-band photographs are shown in figure III-1. In the red wing of H_α , the filament F1 was not visible, however greater Northern portion of filament F was visible at H_α + 0.3 and H_α + 0.5Å°. Only an arc shape
### TABLE III-1  LIST OF TWO RIBBON FLARE OCCURRED IN SPOTLESS REGIONS OR IN REGIONS WITH VERY SMALL SPOTS.

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<th>Location</th>
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Sequence of development of Ti flare in spotless region (Heli. Ho - 16852) taken in Hα - line centre and off band on 17 May, 1966. Note filament activation (F and F1) before and during the flare in Hα - on band (a-c) and off-band Hα - 0.3Å (d), Hα - 0.5Å (e), Hα - 1.0Å (f) and Hα - 0.3Å (g) Hα - 0.5Å (h), Hα - 1.0Å (i). L indicates loop joining filaments R, S, & 62.

Figure III-1
of this filament F (N-E portion) was visible at H +1.0A°. These observations in "off-band" indicate that filament activation started about 3 hours before the occurrence of the flare and activation continued during the flare.

The flare ribbon R₂ was observed crossing over the fibrils (figure III-1 (c)) which were clearly visible near S-W end of the filament F₁ (III-1b). The fibrils were not observed again when the ribbon moved away from its position of appearance. Shown in figure III-2 are line drawings of plage, filament, flare ribbons and loops etc. The filament F almost restored back around 1100 UT after the end of the flare. A bright loop shown in Figure III-1 was observed from the beginning of the flare. The loop became brighter with the progress of the flare. One leg of the loop appeared anchored in Ribbon R₂ and it was observed that ribbon was brightening only after getting material through this loop. In figure III-2, a diagram is drawn, using Hα "on-band" and off-band photographs, to show the loops observed during the flare. The east end of ribbon R₂ is connected with west end of ribbon R₁. Similarly East end of R₁ is connected with west end of R₂. The loops are drawn as seen in the sky plane in the line center Hα.

The total calcium plage area of both regions - 16852 and 16853 reported in S & G data on 16 May 1980 was 800 \(10^{-6}\) of the solar disk; increased to 1600 on
Figure III - 2.

A line drawing showing the development of TR flare on 17 May 80. Note filaments (F and F1) activity and expansion of loops as the ribbons R1 & R2 separate from each other.
Figure III - 3. A magnetogram of the McMath region 16852 and 16853 taken at KPNO. The negative polarity of region 16852 is surrounded by positive polarity. Note an inverted positive polarity (arrow) at the center of the negative polarity.
17th and reduced to only 1100 on 18th May, 1980, indicating that the area of the plage on the day of the TR-flare was significantly more. Shown in Figure III-3 magnetogram taken at KPNO on 17 May 1980 at 1738 UT for the regions 16852 and 16853. In the region 16852 the negative polarity is surrounded by positive polarity, and near the centre of the negative polarity region an inverted positive polarity is also seen. It seems that the existence of such inversion of field polarities (intermingling of polarities) cause filament activation and perhaps flare emission too.

2.1.2 TR flare of 25 Feb. 1979

An emerging flux region (EFR), McMath region No. 15849, observed at S20E60 around 0400 UT on 25 Feb., 1979. The EFR was close to the east limb where a quiescent prominence was visible. A large filament was also seen between EFR and eastern limb which extending behind the limb. Shown in figure III-4, are H-alpha filtergrams showing the development of this event. In first two filtergrams in Figure 4(a) and 4(b), a thin dark filament was visible crossing the plage region. The large filament near the limb is indicated as F2 and the thin curvilinear filament is shown as F1 in figure III-4. A two-ribbon flare was observed at 065526 UT (Figure 4c),
Figure III-4

Sequence of T. flare development in sunspot region (VcMath Nr 15386 on 26 Feb.) where in the filament centre. Prior to flare start filament F2 showing activity. Later eruption of filament F2 at a distance (0655 UT) of the east limb and reappearance of filament F1 (of F. 1.75") and clearly visible on 27 Feb. (h). The F. was not visible on 26 and 27 Feb. (g and f).
which started earlier and the beginning of this flare was missed. Nevertheless the following important points were observed.

1) Since the beginning of the flare was missed, the filaments F1 and F2 were not clearly seen when observations started (0655:26 UT) as shown in figure III-4(c-f).

2) On the E-limb, an eruptive prominence (eruption of filament F2) was seen. This eruptive prominence was decaying as the flare also decayed.

3) The large filament F2 did not appear after eruption and was not observed even on next two days 26 and 27 Feb. 1979 (cf figure III-4g and 4h respectively).

4) A few remanents of filament F1 could be seen in some good filtergrams during the flare. Nevertheless, this filament F1 restored completely on the next day, 26 Feb. 79, as seen in figure III - 4 g.

5) On 26 Feb, the active region showed very small sunspots (barely visible) on the disk in region 15849.

The magnetic field observations of the region (McMath No. 15849) on 25 Feb. 1979, during the TR-flare period were not available, so I used magnetogram of Mt. Wilson taken on 25 Feb. at 17:46 UT for superimposing
flare ribbons on the magnetic field. Similarly for other events also, I used magnetic field observations either from Mt. Wilson or KPNO. Thus the superimposition of flare ribbons on the magnetic field of the region, about 12 hours earlier or later, is only approximate. The superimposition of flare ribbons on the magnetogram is made to get an idea about magnetic field configuration of the region.

In Figure III-5a, I have shown the two ribbon H-alpha flare in EFR active region superposed on magnetogram of Mt. Wilson taken on 25 Feb. at 1544 UT and in 5b, 5c, 5d magnetograms obtained at KPNO of EFR on 24, 25 and 26 Feb. 1979, are shown. The magnetogram of McMath Region 15849 showed negative preceding polarity and positive following polarity. Further a negative polarity was seen approaching from the east limb of region 15850 towards the following positive polarity. The negative preceding polarity of the following region 15850 appeared separated from the following positive polarity of the preceding EFR 15849, by a large filament F2. The flare ribbons were clearly visible in EFR, as one in negative and other in positive polarity. In figure 5c is shown an emerging magnetic flux region of positive polarity and a small pore of opposite (negative) polarity by an arrow. These fields appeared to have emerged from below the filament F1. From H-alpha observations and magnetic field configuration, the flare event is interpreted in view of Canfield
Figure III 5(a). Superimposition of H\textsubscript{x} flare ribbons (hatched) on the magnetogram taken at Mt. Wilson on 25 Feb. 79 at 1746 UT.
The Kitt Peak National Observatory magnetograms of
The arrow indicates emerging flux region (CFR) on May 25.
et. al, model of flare (Canfield et. al, 1974). The newly emerged magnetic flux below the thin curvilinear filament F1 of EFR region 15849 seems to be the main cause of filament eruption F1 and the appearance of the flare according to model of Canfield et. al, (1974), which has been discussed in chapter I. Thus this flare was perhaps a manifestation of interaction between the new and old flux and, when its electric current density exceeds a critical value, rapid magnetic field reconnection takes place. Electrons are then accelerated to high energies following the magnetic field lines down to the chromosphere where they produce several bright H-alpha knots. Magnetic energy is continuously released as the reconnected filament fields untwist.

2.1.3 TR-flare of 9 May 1979

Region history

An old sunspot region appeared on 2nd May 1979 on the solar disk in McMath No.15986 at N20E63 with bipolar structure. The sunspots were not visible on the disk, only faint bright plage was visible on the disk. From the Solar and Geophysical Reports, it is found that in this region only one spot of single polarity was seen on the disk on 5th May 1979 and since 6 May onwards only plage was visible and no spot. A huge quiscent filament F was seen preceding the NW of this region. Since 5th
May, the plage region was seen encircled by a thin faint dark filament F1. The circular filament F1 became more and more clear around 0433 UT of 9 May 1979. (figure III-6b), but after the flare at 0730, the circular filament F1 completely vanished and was not visible on 10th May.

**Flare - observations in H-alpha**

On 9 May, 1979 in McMath Region 15986, not a single spot was visible. The location of the region was N20W20 on the Solar disk. The morning observations of the region at 043410 UT showed appearance of a bright arc loop structure below the circular filament F1 at its NW portion as shown in figure 6 (b) indicated as 'L'. This bright arc structure was not seen on the previous day (8th May) around 0922 UT.

The observations of this region were not made between 0433 to 0733 UT on 9 May 1979 and it seems that during this period of 3 hours some interesting filament activity took place, which triggered the flare. Nevertheless, H-alpha observations of this region beginning from 073310 UT showed following.

1) The bright flare knots were visible around the circular filament, although large portion of this filament F1 was disrupted and only a little was left as showing figure -6c.
Figure III-6
Sequence of $H_\alpha$ filtergrams showing filament (F1) activation prior to and during the flare development in spotless region (McMath region 15966) on 9 May 1979. L (043410) denotes bright loop.
2) Among the various bright flare knots, one brilliant kernel seen located near the loop 'L' and another bright knot, at the center of the circular filament F1.

3) After 0733 UT, the remaining material in filament F1 showed interesting activity. It separated into two or three threads and the faint dark circular shape filament again reappeared.

4) A new small filament was seen growing south of the F1 and appeared to cross it (F1) around 0739 figure -6(d).

5) Around 0743 UT, major part of the filament F1 restored back, although not exactly in the same circular shape but in the form of hooks around the earlier shape. The flare knots reduced in intensity around this time.

6) The filament material was unstable and it was showing considerable activity during the flare.

7) It appears from figure III-6 (g) around 0750 UT that the material was ejecting out from three locations, like vertices of a triangle, among which one was near the foot of the loop 'L'. During motion of filamentary material, new bright knots were also visible in the region.
8) Around 0809 UT, the flare completely decayed. Only a faint bright point at the position of loop 'L' (Figure IV-6) was seen. However, at this stage a portion of the filament was observed and plage was visible in almost circular shape.

9) Between 0809 and 0815 UT, the remaining filament material was seen to move from south to north inside the region and finally moved away around 0817 from the region.

10) After the disappearance of the filament F1, flare knots appeared again around 0823 UT and at the same location in almost circular shape. The bright knots spread over the region, which seems to form a Two Ribbon flare but the ribbons did not show any separation with time. Thus the two ribbon shape is ambiguous in this flare.

11) Around 0837 UT, a small filament observed which vanished within five minutes (III-6-j)

12) The flare decayed around 0847 UT and the region appeared quiet at 0911 UT. However, a faint dark circular shape filament was seen on the next day i.e. 10 May 1979.

Shown in figureIII-7 are magnetograms of this active region taken on 6th and 7th obtained from KPNO and
Superimposition of $H_\alpha$ flare kernels (hatched) on magnetogram taken at Mt. Wilson on 9 May 79. The magnetograms of 6 and 7 May were taken at KFNO. Note the changes (arrow) in magnetic field configuration of the region.
on 9th and 10th from Mt. Wilson. It is clear from these magnetograms, that the magnetic field configuration completely changed from 6 through 10 May, 1979. It seems that the appearance of bright arc indicated as L, near the circular filament F1 (cf. figure 6 b) was perhaps due to emerging magnetic flux (EMF) under the filament or at least some indication of the change in magnetic field was noticed on 8 May. An examination of the magnetogram taken on 9th, after the flare show clearly that new structure appeared to have joined the earlier magnetic field configuration. On 10 May the magnetic field configuration seems to further change. It may be inferred from the temporal variation of the filament (appearance and disappearance) and the flare knots, were perhaps due to frequent changes in magnetic field.

8.1.3. TR flare of 12 April 1979

The McMath plage region 15934 was flaring at N12W05 when our observation were started at 0420 UT on 12 April, 1979, thus the beginning of the flare was missed. Following, this non-spot region and close to it a highly active McMath region 15933 was existing. The first frame showed that in the beginning, south-west ends of flare ribbons were almost joined together. From the beginning of the observations, flare was seen accompanied with H-alpha bright loops. This IB importance two-ribbon flare peaked around 0425. Several bright points were
observed in the H-alpha loops and bright material was seen moving along the loops. The figure III-8 shows, H-alpha sequence of development of flare. A small thin dark filament F was visible near the flare ribbon at 042309 UT. This filament displayed activity throughout the flare existence. This filament F expanded and started to move towards North in the beginning and thereafter towards North-West, but it did not disappear from the region. In the beginning only one bright loop L1 was observed connecting a brilliant kernel B1 of the west ribbon to kernel A 2 of the east ribbon. It seems there were two loops, the second loop L2 was perhaps not clearly visible due to filament F in the chromosphere. This loop L2 appeared to join B2 kernel of the west ribbon to A1 of the east-ribbon and this became clear on later frames. This situation of intermingled loops implied that both kernels on each ribbon belong to opposite polarities and thus the region must have mixed polarities. To confirm this, I examined the magnetogram taken on 12 April 1979 at Mt. Wilson Observatory. The photospheric magnetic field, as seen from Mt. Wilson magnetogram as given in S & G data shows that this region had, in fact, mixed polarities. Shown in figure III-9a is line drawing of the location of flare ribbons on the magnetic field map of the region,
Figure 11-8

A sequence showing the development of 16 flares in an active region (Komm. No. 16934) on 12 April 1979. Note filament activation (F) and expansion of loops with separation of filaments. The arrow (043648) indicates disappearance of major portion of filament F which disrupted prior to flare occurrence.
Figure III-9. Superimposition of Hα flare ribbons (hatched) on the magnetogram taken at Mt. Wilson on 12 April 79 at about 2400 UT. Note mixed polarities in the region.
As the beginning of the flare was missed and the region was not also observed earlier neither on 12th nor on previous days, thus the actual preflare situation of the region is not known. However, the appearance of a long filament F1 at 043519 UT on the North-east side of the region shows that, perhaps, the flare accompanied or followed the disruption of the filament F1. The flare decayed at 0435 UT.

The magnetogram of this region is very complex, the region had a strong positive field gradient in which negative polarity appeared at several places and thus giving a mixed polarity configuration to the region.

2.2 Single spot Regions

2.2.1 TR flare of 30 Dec. 1978

The McMath Region 15746 was observed around 0343 UT on 30 Dec. 1978. In this region only one spot P and following plage, crossed by a curvilinear filament F were observed. Shown in figure III - 10 are H-alpha filtergrams of this region from 0343 UT to 0809 UT. The shape of the filament changed and in particular the N-E portion showed greater activity before the flare. The flare began around 0542 UT as several bright nodules joining together to form a spiral S-shape around 0545 UT and within 1 to 2 minutes it was observed that the flare structure broke up into two ribbon near the middle
TABLE III-2  LIST OF TWO-RIBBON FLARES OBSERVED IN THE REGIONS WITH SINGLE MAJOR SUNSPOT.

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Figure. III-10. Hα sequence of TR flare development in a region with a single major spot (McMath region 15746) on 30 Dec. 1976. Note filament activation (F) and its reappearance after flare decay (043250).
Superimposition of Hα flare ribbons (hatched) and spot (dark) on the magnetogram taken at Mt. Wilson on 30 Dec. 78 at 1805 UT. The other magnetograms (top) were also taken at Mt. Wilson on 29, 30 & 31 Dec. 78. Note the changes (arrow) in magnetic field configuration of the region.
of S. Both ribbons then started to separate from each other. A bright kernel appeared at the boundary of the spot which did not show any motion. The eastern ribbon R1 appeared much brighter than the western ribbon R2. The flare peaked around 0558 UT. During the decay phase post-flare loops in emission were observed during 0650 to 0810 UT connecting bright kernels in opposite ribbons (cf figure III-10 at 0720 UT). Around 0800 UT only SE portion of the filament could be observed, however, on the next day; 31 Dec. 1978, the filament appeared elongated and took a different shape.

Shown in figure III-11 are magnetograms for 29th, 30th and 31st Dec. 1978 and superimposition of H-alpha features on magnetogram of the region 15746, indicate that the flare occurred in region of strong field gradient, between opposite polarities.

2.2.2 TR-flare of 17 December, 1976

At the start of our observations at 0600 hours UT, in the McMath region 14556, a small spot p and a long curved filament F was observed with slight brightening extending from each end but lying on opposite side of the filament. Shown in figure III-12 are H-alpha filtergrams of the development of the TR-flare. At 0618 UT the filament showed activation which was very prominent in its middle portion. Around this time,
another dark filament F1, developed adjacent to the existing filament F. The new filament F1, which was quite broad at one end and narrow at the other end, showed clearly twisting of the field lines. As the time progressed the old curved filament F continued to show the oscillatory motion, perpendicular to its length while the new filament F1 extended in length and became more prominent. By 0920 UT this new filament F1 disappeared, however, the old filament F continued to show movement near the centre. At 1005 UT the filament F got completely distorted from its initial shape and the bright flare nucleuses appeared on both sides, along its length. The brightness on the northern side i.e. towards spot side, started at both the ends of the filament and extended along it; while on the southern side it started near the middle and spread in both the directions along the filament. Around 1010 UT, a bright surge appeared from the end of the filament which was nearer to the spot. The velocity of ejection of this surge was of the order of 100 km/sec. The ejection of bright surge was followed by the ejection of dark matter along the path of the surge. The ejected dark matter was a major part of the filamentary material, as the filament was not clearly seen on the subsequent frames. By the time, around 1017 UT, this dark matter completely vanished, the brightening on both sides of the filament developed and appeared as a well formed two-ribbon flare configuration. Both the ribbons started to move away from each other.
Figure III-12

Hα filtergrams of McMath region 11566 showing filament activation in F & F1 and development of T-c-Ribbon flare on 17 Dec. 1976. The arrow (1017) UT indicates ejection of dark material.
Figure III-13. Superimposition of Hα flare ribbons (hatched) and sunspot (dark) on the magnetogram taken at Mt. Wilson observatory on 17 Dec. 76. Also shown magnetograms for 16, 17 and 18 Dec. 76. Note changes in the magnetic field configuration of the flaring region.
The plage in the region showed various changes in area and brightness as seen in H-alpha filtergrams, before the occurrence of TR-flares. However, from S & G Data reports it was found that the area of the region was 900 millionth of solar disc on 16 Dec. 1976 and it increased to 1200 millionth solar disc on 17 Dec. 1976. This McMath region 14558 was a bipolar region on 17th but it became unipolar on 18th Dec. 1976. The magnetograms showed in figure III-13, indicate that on 16 December, 1976 in the neighbourhood of the preceding positive polarity a small negative polarity field was observed. Between the two following negative polarities, a small positive polarity field was seen. Also inside the major negative following polarity, an inverted positive polarity was observed. On 17 Dec. 1976, preceding and following positive polarities appeared to join, also the inverted polarity was not seen. Further, observed on 17 Dec. 1976, two small negative polarity fields on opposite sides and in proximity of the preceding positive polarity were not seen on 18 Dec. 1976, rather the preceding positive polarity itself broke into two parts on 18 Dec. 1976. The active region became quiet on 18 Dec. 1976.

2.3 Complex Spot Regions

Given in Table III-3 is a list of TR-flares occurred in complex active regions.
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2.3.1 **The TR-flare of 30 Dec. 1976**

I have studied the development of the region, McMath No. 14579 in detail as H-alpha observations were available since 24 December, 1976. In figure III-14, is shown H-alpha filtergrams of the region from 24 Dec. 1976 through 31 Dec. 1976. Before the occurrence of a great TR flare on 30 December, 1976 around 0540 UT, the region continuously showed activity since it's appearance on 24th. The filaments F and F1 were changing their structure by breaking, elongating and disappearing. The region produced several minor flares before the TR-flare of 30 Dec. 1976. The dark fibrils east of preceding spots were appearing and disappearing in the region since 29 Dec. 1976. The bright plage was continuously expanding till 30 Dec. 1976.

The study of this event indicated that several days before the occurrence of the great TR-flare of 30 December, 1976, the filament in the region showed considerable activity. The plage also showed extension and became brighter before the flare. Several dark fibrils were growing and decaying, many hours before and during the flare. The region also produced subflares before the TR flare of 30 Dec. 1976. The magnetogram of 30 Dec. 1976 taken at KPNO showed mixed polarities in the region. The preceding spots were of negative polarity.
Figure III-1A

Ha - Filtergram of McMath region 14579 from 24 through 29 Dec. 1976. Note filament activation and variation in plage area and brightness.
Figure III-14B

2.3.2 Homologous TR-flares on 9 Nov. 1979

The McMath active region 16413 was observed on 9 November 1979 at S15W01. A flare of importance 1B was already in progress near SW of the preceding spot around 0310. The flaring region gave bright and dark surges, shown in figure III-15(a). Around 0323 UT the flare ribbons were clearly visible and separated from each other. Another flare appearing as an inverted U, was observed around 0547 UT and at the same location indicated as in figure III-15a where earlier a flare had occurred. Around 0554 UT, the two ribbons joined by flare loops were clearly observed. Before this flare completely decayed around 0600 UT, a 2B importance class flare occurred again at the same location, and almost of the same shape (i.e. inverted U). The bright loops were also observed joining the flare kernels. During flare decay period around 0618 UT several flare loops were observed. Towards the end of the flare (0629 UT) a dark and small filament appeared between the two ribbons.

The magnetic field of the region showed that the preceding spot was of negative polarity while the following spot was of positive polarity. The location of the flare activity showed field reversal near the preceding spot, perhaps, this inverted polarity island was responsible for mass ejection and flare activity. The reoccurrence
Figure 111-15

H* - filtergrams of a complex spot group, McMath region No. 16413 on 9 Nov. 1979 showing recurrent homologous TR - flare activity. The arrow in 111-15 b and c indicates ejection of bright and dark material.
Figure III-16. Superimposition of $H_\alpha$ flare kernels (hatched) and sunspot (dark) on the magnetogram taken at Mt. Wilson on 9 Nov. 79 at 2215UT. Note inverted polarity at the location of the flare.
of TR-flares in quick succession and their homologous nature indicate that energy built-up required for the flare was recreated in quick succession. If the flare energy is due to the magnetic field, then perhaps temporal (periodic) changes in magnetic field was taking place or a continuous magnetic field reconnection was in progress which became faster prior and/or during the flare. The magnetogram is shown in figure III-16.

2.3.3 Typical flares generating Active region

The active region Boulder No. 2363 (Hale Region No. 16740) appeared on 26th March 1980. It produced several flares of importance ranging from SB to 3 B. Among various flares, the important flares are of 28 March 1980 which produced rarely observed inverted 'U' shape Type II-radio burst (Markeev et al., 1981; Bhatnagar et al., 1982) and on 29 March 1980 gave rise to a gamma ray burst; and on 3 April, a TR-flare which produced microwave burst of about 1000 sfu and on 7 April, an expanding loop which produced a coronal transient on the west limb. In this section, the history of this region is given in view of the changes those occurred prior to and during TR-flare of 3 April. Shown in figure III-17 are H-alpha filtergrams of the region from 1st April through 3 April. The broken and curvilinear long filament F appeared crossing the plage north-south in the region showed considerable
activity throughout the period of observations on 1st April, 1980. The filament material ejected out in the North-West direction. The filament motion is in off-band sequence and shown in figure III-17. On 2 April, filament motion at the North end, subflares and extension of plage were observed. The north end portion of the filament ejected out around 1000 UT. On April 3, at 0325 UT only SW curved portion of the filament was visible. The plage was not intense and extended, but around 0430 UT the plage expanded and started to become brighter, in the region east of the following spot. Around 0637 a flare of importance 2B occurred in the region and spread over the filament position. Before this flare completely decayed and again developed to became a two-ribbon flare to reach peak intensity around 0706 UT. The dark filament was visible until 0700 UT thereafter it vanished. As the ribbons were separating away from each other, the dark filament was seen to be reappearing. A bright mass ejected around 0632 UT was observed to move initially with a velocity of 60 km/sec., which increased to 330 km/sec., at about 0639 UT. During the flare activity, dark and bright surges were observed to eject cut from the region towards the west of the spots.

The magnetogram of this region (figure III-18) indicate that inside the surrounding negative polarity, a strong positive field exist and many small regions of reversed polarities appeared at the boundary of the
Sequence of Hx - filigree of Hale region 16740 showing filament activation (arr w) on 1st April 1980 (a-d); on 2nd April 1980 (e-f) and development of TR-flare on 3rd April 1980 (g-l).
Figure III-18. Superimposition of $H_\alpha$-flare kernels (hatched) and sunspots (dark) on the magnetogram taken at Mt. Wilson on 3 April 80 at 1729 UT. Note strong positive polarity surrounded by negative polarity.
negative polarity. From the magnetogram it indicates that the region was very complex magnetic field region.

2.3.4 **TR-flares in Hale plage region 16772 on 17 and 18 April 1980.**

In the Hale plage region 16772, two TR-flares were observed on 17 April and 18 April 1980. Shown in figure III-19 are H-alpha filtergrams of the region and the development of flares. The low contrast and small spots were observed in the preceding groups. A long spiral and curvilinear filament \( F \), crossing the plage almost in the middle was seen on 16 April, 1980 around 0938 UT (figure III-19(a)). Around this time a flare of importance 1N was in progress.

On 17 April, around 0338 UT, the filament was not seen and only bright plage nodules were observed. Around 0349 UT the northern plage brightened and became more intense than the surrounding plage region and the filament had almost disappeared. The brightening of the plage was increasing with time. A thin and small filament appeared in the middle of plage around 0420 UT and about 0430 UT several brilliant points appeared in the region to give rise to the TR-flare, which peaked around 0442 UT. Another thin and long curvilinear filament \( F1 \) was observed between the two-ribbons of the flare. The
bright mass ejection at the NW end of the eastern ribbon was seen from 0440 UT. Around 0505 UT, the new filament F1 was more clearly visible.

On 18 April around 0200 UT, both filaments F and F1 were clearly visible and appeared almost joined together. The plage area appeared extended and was much brighter than the previous day, on 17 April, after the flare. The structure of the field appeared changing as evident by the filament activity seen around 0430 UT. The plage was more intense around 0600 UT and in particular at the location where flares occurred on 16 and 17 April. At 0623 UT on 18 April a great TR-flare started to reach a maximum at 0640 UT. During the development of flare, the filament showed considerable activity, it was turning, expanding and disappeared in some places. In this TR-flare, ribbons showed appreciable separation. At the end of the flare around 0710 UT, the plage in the region was less intense and the filament was much darker. The occurrence of TR-flares during 16 through 18 April, in this region took place in a particular location only, indicating homologous character of these flares. The last flare observed on 18 April was the most energetic one.

The preceding polarity of the region was positive and the following polarity was negative. At the northwest location of the region, where flares occurred some
Figure III-19A

Sequence of Hα - filtergrams of Hale region 16772 showing filament activation (F) and development of TR flare on 17 April 1980 (b-h). The first picture is taken on 16 April, 80 (a).
Figure III-198
Sequence of Hα - filtergrams of Hale region 16772 showing filament activation F and F1 and development of TR flare on 18 April 1980.
Figure III-20. Superimposition of the flare kernels (hatched) and sunspot (dark) on the magnetogram taken at Mt. Wilson on 17 April 80 at 2208 UT.
reversed polarities were also seen at the boundary of the negative following polarity. The magnetic field configuration of the McMath region 16413 on 9 Nov. 1979, which produced recurrent homologous flares on 9 Nov. 1979 (cf 2.3.2), was almost similar to the field configuration of this region, shown in figure III-20, responsible for homologous flares on 17 and 18 April 1980.

2.3.5 TR-flares on 20 February 1981

Two TR-flares were observed on 20 February 1981 in a complex active region Hale No. 17461 and 17462. The region showed extended and intense plage around 0320 UT on 20 Feb. A system of faint dark and curvilinear filaments appeared crossing the plage. A minor SE flare in the east of the following spot was observed around 0500 UT. Around 0540 UT a TR-flare of importance 1B occurred between the preceding ...and the following spots. This flare reached its peak around 0557 UT. In figure III-21, sequence of flare development is shown.

The flare occurred at the location (N20W25) where the curved filament was showing considerable activity. After the decay of the flare at 0620 UT, a portion of the filament was again clearly visible. Meanwhile, west of the preceding spot, plage extended and became much intense around 0635 UT. At this location (N20W50) a
large flare with ribbons and loops appeared around 0640 UT. The filament was covered by flare ribbons and became visible during flare decay. The loops expanded with the progress of the flare. The material motion along the loops was clearly visible. In fact, this flare formed as four ribbons - two sets of two ribbons. Among four ribbons, two were opposite and parallel directed along NE-SW, while the other two ribbons were directed along N-S and this second two-ribbon flare was below the thick dark filament. This whole situation together with mixed loops (arcade of loops) was clearly visible around 0705 UT. The flare ended around at 0730 UT. The magnetogram (figure III-22) of the region showed that this region was of mixed polarities. Both flares 0540 and 0640 UT occurred at the location of reversed polarities.

Thus it seems that complex spoc groups with mixed polarities or in which polarities intermingle or reversed polarity appears, give strong and higher importance TR-flares. They show extension of plage and increase in it's brightness, filament activation, ejection of bright and dark surges and fibril activity before and during the occurrence of a great TR-flare. Many small flares sometimes are observed before the occurrence of TR-flare. Generally, after the occurrence of great TR-flare, the region becomes quiet. However, recurrent TR-flare activity is also observed. Nevertheless in such
Figure III-21A

Hα - filtergrams showing activation of filament indicated by an arrow prior to TF flare in complex Hale region 17462 on 20 Feb. 1981. The first filtergram is taken on 19 Feb., 1981 (a).
Figure 111-21B

Filtergrams showing development of TR flare (arrow) in halo region 17462 on 20 Feb. 1981.
Figure III-22. Superimposition of Hα flare ribbons (hatched) and loops (dark) on the magnetogram taken at Mt. Wilson on 20 Feb. 81 at 1849 UT.
regions too, after the occurrence of last and higher importance flare the region becomes quiet for a few hours.

2.3.6 Some flares with multiribbons

In complex spot groups, sometimes flares occur with more than two-ribbons called Multi-Ribbon flare. Shown in figure III-23 are H-alpha filtergrams of four such multiribbon flares. I have not described in detail these multiribbon flare occurrence in this section.

On 18 Feb. 1979, a three ribbon flare of importance 2B occurred at 0640 UT in the McMath plage region 15830. This region produced several higher importance flares on 16 Feb. 1979. The three ribbon flare of 18 Feb. 1979 was an impulsive flare and showed distinctly a veil emission around it. The veil emission seems to emanate from the flare core and appears first near the time of the beginning of the flare (Martin, 1979). The area and brightness of veil increased during the flash phase and thereafter it rapidly faded. The flare occurred in mixed polarities. The polarities in the region were intermingled.

On 6 Oct. 1979, in complex active Boulder region 2032 a great flare of importance 3 N with many strands, was observed around 0712 UT. A break in the dark filament in the active region was observed and after
Figure III-23
the flare maximum at 0714 UT the filament attained its pre-flare shape and position. This region also showed mixed polarities.

A flare with three parallel ribbons was observed in Boulder Region 2470 on May 28, 1980 around 0217 UT. The two flare ribbons B and C (figure III - 23 (c)) were connected by a bright loop and about 20 minutes after the flare maximum (≈ 0217 UT) all the three flare ribbons A, B and C were connected by arch shaped post flare loops. This flare occurred in a region of strong magnetic field gradient between the fields of opposite polarity (Bhatnagar, Jain and Shelke; 1981)

A multi-ribbon flare was observed on May 10, 1981 around 0535 UT. The region was very complex containing many sunspots and system of several curvilinear filaments. In figure III-23 (d) an H-alpha filtergram of this flare is shown.

The multi ribbons form because in these region more than one filament exist. Thus a complex region with a system of curvilinear filaments may produce multi-ribbon flares.

3. Orientation of Flare Ribbons

It is well established that in two-ribbon H-alpha flare bright nodules join to form a ribbon structure on
the opposite side of a dark filament. Many a times the ribbons have straight shape but two-ribbon flares also have curvilinear shapes. In this section, I have made an attempt to determine the orientation of flare ribbons occurred in different regions.

3.1 Orientation of flare ribbons in spotless Regions

Dodson and Hedeman (1970) showed that essentially all large Two-Ribbon flares in old active regions develop as a transformation of a dark filament. The ribbons develop along and on both sides of a dark filament which may disappear. Shown in figure III-24 are drawings of the flare ribbons with respect to the magnetic polarity and the position of filament in spotless regions. It is clear from the figure that the shape of flare ribbon in spotless regions is described by the shape of the existing filament in the region. The filaments had curvilinear, circular and almost straight shape in different spotless regions. The ribbons were observed to bend where the filament was bending. The ribbons developed on opposite side of straight portion of the filament were observed, as parallel branches (figure 24b,f). However, the ribbons developed in the region with curvilinear filament (figure III 24, a,e) appear parallel upto some extent. But the flare ribbons developed around circular filament (figure 24-c) do not appear parallel. Many a times the
Figure III-24. A line drawing showing orientation of flare ribbons in the spotless region and about 12 hours later field configuration. Note shape of flare - ribbons and filament structure.
flare ribbons in spotless region remains parallel during their separation, but when the distance between the two points on opposite ribbons is determined with respect to time, it is revealed that the separation does not increase uniformly with time to maintain parallel shape. This is because all the portion of the ribbon do not move with the same velocity. This has been described in section 5 "Separation velocities of ribbons".

The opposite sides of the flare ribbons lie in region of opposite polarities, and the dark filament in the region of $H_\parallel = 0$ line. The McMath region No. 15934 and 17307 in which TR-flares occurred on 12 April 1979 and 9 Dec. 1980 respectively showed mixed and inverted polarities. However, as shown in the previous section, the regions which produce TR-flares show complex magnetic configuration.

3.2 Orientation of flare ribbons in Single Spot Regions

The shape of flare ribbons in the case of single spot regions is similar as in the case of spotless region i.e. the curvilinear and straight. In these regions generally one ribbon appears towards the spot side. In figure III-25 drawings of the flare ribbons and their orientation with respect to the filament and spot are shown. In all cases the flares were observed following
Figure III - 25. A line drawing of flare ribbons in single spot region and field configuration about 12 hours later. The ribbons formed east to the preceding spot.
to the spot. In class 1 and higher importance flares it was observed that during separation of ribbons at least, some portion of the ribbon, which was towards the spot, seems to stop when flare ribbon reach the spot (figure 25 c, d). As shown in figure III-25d, flare ribbons may have parallel structure, but it is not necessary because in a few cases (figure 25 a, c) a clear cut parallel situation of ribbons was not observed. The polarities of ribbons are marked in figure III-25.

3.3 Flare Ribbons in complex sunspot regions

The appearance and behaviour of ribbons in complex sunspot regions is different as compared to spotless and single spot regions. In figure III-26, drawings of flare ribbons in complex sunspot groups are shown. In these active regions, magnetic field is complex, either an island of inverted polarity forms or some new magnetic flux emerges or temporarily mixed polarities exist. In all 20 cases of complex active regions it was found that mostly the filament had very complicated structure and appeared joining several irregular filaments. The shape of flare ribbons was also very irregular, appeared broken and complicated. The two flare ribbons in these cases are generally not parallel, however some portion of the flare may appear parallel. In these regions different spots were observed with opposite polarities, as shown in
Figure III-26. Line drawing showing orientation of flare ribbons in complex sunspot active regions. The shape of ribbons is complicated and they are embedded in spots. N and S denotes, North and South polarities of spots.
figure III-26, thus different kernels were also observed to lie, in mixed polarities. As shown in section 5, the motion of the flare ribbons seems to be influenced by sunspots in these region, as the ribbons approach the spots. In the case of intense flares, part of the ribbons, sometime penetrated into the umbra of the spots.

In addition to above varying characteristics of wo flare ribbons in different regions, one common and important characteristic property of flare ribbons, is that, in most of the regions the total length of different H-alpha brightenings which form one ribbon was greater than the total length on the opposite side. The ratio of this total linear dimension of longer to shorter ribbons, varied from 1.2 to 1.8 in different flares.

Among those cases in which beginning of the observations were available, some ribbons show a 'Y' shape (phase) and then started to separate away from each other. In some cases after 'Y' phase ribbons became parallel.

4.0 Development of flare ribbons

The H\textsubscript{\lambda} -TR flare appears first as several brightenings which expand in area during the development. In general, the area of the flare increases rapidly to reach the peak value, but decreases slowly. Thus in TR-
flares the growth period is smaller (about 2-20 minutes) and the decay period is longer. In this section, I have described the growth curve of flare ribbons. In a few cases, I have given growth curve of individual $H\alpha$ - kernels which form the ribbon. To determine area in millionth of solar disk, I used the formulae given in chapter II.

4.1 Spotless Regions

The development of TR flare of 17 May 1980, is shown in figure III-1 and the area of these ribbons in millionth of solar disc is shown in figure III-27 (a). The time of maximum area attained by both ribbons was around 1014 UT, however, ribbon B attained the maximum area of about 110 millionth of solar disk (M), while ribbon A could attain only 90 millionth of solar disk. The ribbon B showed another maximum around 1026 UT to attain maximum area of about 96 M (millionth of solar disk), while the ribbon A showed a minor second maximum of area 84 M (millionth of solar disk) at 1023 UT. The decay pattern of both ribbons was similar.

Sometimes, the growth curves of the two ribbons are different as in the case of 22 Nov 1980, TR-flare, shown in Figure III-27b. Here the intensity of one ribbon was approaching towards maximum, while the intensity in other was declining. The features 1 and 3
Figure. III - 27. Growth curve of flare ribbons and flare kernels in TR-flares of May 17, 1980 and Nov. 22, 1980 observed in spotless regions. Note that area of each ribbon or each flare kernel is not same.
formed one ribbon while feature 2 was single in opposite ribbon. The feature 1 reached the maximum area (140 M) at 0600 UT and feature 2 around the same time reached a smaller area (40 M) from it's initial higher area of 80 M. However, the feature 2 again attained a second peak (60 M) around 0605 and then continuously showed a decrease, while the features 1 and 3 showed only a decline. The maximum area of feature 1 is almost 1.5 times the maximum area of feature 2 of the opposite ribbon and the feature 3 of the same ribbon.

4.2 Major single spot regions

The flare of 17 Dec. 1976 was discussed in section 2.2.1 and the orientation of it's ribbons is shown in figure III-25. The area-growth curve of each individual ribbons A and B is shown in figure III-28(a). In each ribbon four Hα flare kernels were identified. It is clear from figure III-28 (a) that the ribbon A peaked around 1017 UT and attained the maximum area of 90 M. After reaching the maximum (ribbon A), the area reduced to a lower level of about 60 M, at 1021, UT, however around this time the ribbon B showed peak area of 102 M. The Ribbon A again attained a second minor peak around 1027 UT and then decayed, on the other hand, the area of the ribbon B which had greater area at every instant as compared to A, continuously decreased.
Figure III - 28 (a) Growth curve of two flare ribbons A and B of a TR flare on Dec. 17, 1976 observed in a single spot region.
Figure III-28(b) Growth curve of flare kernels (1 & 2 and 3, 4 & 5) forming two opposite ribbons of TR flare on Dec. 17, 1978 observed in single spot region. Note the dissimilarities in growth curve of each flare kernel.
Shown in figure III-28(b) are the area in millionth of Solar disk of different H-alpha flare kernels identified in TR-flare of 17 Dec. 1978. This figure shows that different kernels of the same ribbon, attained peak intensity at different time. The features 1 and 2 form one ribbon while the features 3, 4 and 5 form another ribbon. Further, their growth pattern was different. Some of them showed two peaks while some showed only one peak and on the other hand feature 2 showed fluctuation in the growth curve. Perhaps, each individual H-alpha flare kernel is a small flare and infact a major flare is an integration of all these minor flares.

4.3 Complex sunspot regions

The TR-Hα flares occurred in complex sunspot groups are very complicated in shape. The flare ribbons are formed from joining many H-alpha kernels. Sometimes more than two ribbons are also visible. In figure III-29 are given, growth curves of various TR-flares occurred in complex active regions. It is clear from figure 29 (a) that both ribbons A and B of TR flare, 30 Dec. 1976, peaked around the same time at 0542 UT and almost attained the same maximum area 124 M and thereafter both declined. Thus the development and decay of ribbons in this flare were almost of same pattern. Such a pattern was not observed in the flare of 2 Feb. 1977. However,
Figure III-29(a) Line drawing showing growth of two flare ribbons A and B of TR flares on 30 Dec. 76 and 2 Feb. 77, observed in spot groups. Note similarity of the growth curve of ribbons of A and B on 30 Dec. 76.
the beginning was missed, so that area time curve, shown in figure III-29 (b) refer only to maximum phase period. The maximum intensity of the flare reached around 0504 UT for both ribbons A & B. At this time the maximum area of the ribbon A was twice the area of the ribbon B at 0504 UT. The ribbon A continuously decreased after 0504 UT, on the other hand, ribbon B showed a minor peak around 0516 UT. Further, the area of the ribbon A remained higher throughout the decay phase as compared to the area of the ribbon B. Thus in this case, as seen in figure III-29 (b), the decay pattern of two ribbons was not similar as their areas were not equal. In the case of flare of 16 April, 1980, the development curve is interesting as the area of the ribbon A was greater than the area of the ribbon B in the beginning from 0541 - 0544 UT, but after 0544 UT till the end of flare, the area of the ribbon A was smaller than the area of the ribbon B. However, as seen in figure III-29(c), both ribbons A and B peaked around the same time at 0542 UT. Further, the ribbon B again showed another maximum around 054630 UT to attain an area 90 millionth of solar disk. During the decay phase the area of the ribbon B was about 1.5 - 2.0 times greater than A. Shown in figure III-29 (d) is the development curve for flare ribbons A and B of 20 Feb, 81 TR flare event. After the appearance of features A and B in H-alpha the feature A started to increase in area, while feature B was reducing in area and thus around 0649 UT, when feature A reached the maximum area of about 160 M, the feature B reached the minimum
Figure. XIX-29(b) Growth curves of flare ribbons of TR flares observed in complex spot groups. Note that each kernel or ribbon behaves as individual flare.
area of about 20 M. After 0549 UT the area of feature A, started to decrease while the area of B showed an increase. After 0654 UT, both features showed reduction in area. In this case, the area of the feature A was higher than B during the rising phase as well as, during the decay phase. Thus the growth characteristics of both features in this case were quite different.

The TR-flare of 3 April, 1980 appeared as several bright H-alpha kernels forming flare ribbons on opposite side of the filament. In this flare the development of two features 1 and 5 of opposite ribbons is studied and the growth area curves for both features are shown in figure III-29 (e). The feature 1 showed two peaks at 0637 and 0640 UT and attained the maximum area of about 45 M and 52 M respectively. The feature 5 showed only one peak at 0640 and attained maximum area 40 M. The area of the feature 1 was throughout higher ranging from 1.2 to 6 times than the feature 5, at different times. The feature 5 showed decrease in it's area in the beginning, while the feature 1 was increasing during this period. After 0644 UT, the feature 1 again started to increase in area, while feature 5 was decreasing in area. The main flare developed after 0650 UT and during this period, the feature 1 reached it's maximum intensity around 0709 UT and attained area of 238 M, while feature 5 peaked around 0713 and attained maximum area 70 M.
In the case of flare event of 18 Feb. 1979, three ribbons were identified in H-alpha (cf. figure III-23). The area of the three ribbons I, II and III are shown in figure III-29 (f). The ribbon 1 peaked first at 0642 UT, after a minute around 0643 UT second ribbon (II) peaked and again after one minute the third ribbon (III) attained the maximum area. However, the ribbon I showed another maximum around 0646 UT. The maximum area of ribbons I, II and III were about 100 M; 90 M and 60 M respectively. The second maximum area of ribbon I was about 130 M. From the beginning until the end of flare the area of I was higher as compared to II, and the area of II was higher than III.

The study of the growth and decay of flare ribbons and flare kernels showed that mostly the area-curves of flare ribbons have dissimilarities. It was observed that either their total areas are different, their peak periods are different and/or their rise and decay characteristics are different. Similarly, the behaviour of individual area of flare kernel was different from the kernel of opposite ribbons, as well as the kernel in the same ribbon. However, in a few cases the growth curve of opposite flare ribbons and flare kernels show some similarities. Thus it seems that in a two-ribbon flare, each ribbon is formed by many subflares, and each behaves as an individual H-alpha flare. Thus the total integrated effect becomes more important because it contains more energy (total of all
subflares energy) as compared to a single flare. Hence, we expect and observe large number of phenomena associated with TR-flares.

5. **SEPARATION OF FLARE RIBBONS**

Various authors (Dodson 1948; Dodson and Hedeman 1960; Valnicek 1961; Svestka 1962; Malville and Moreton 1963) have shown that the two bright flare ribbons separate with velocities of the order of 1 to 10 km/sec. The velocity of separation of flares occurring in spotless regions is either constant or show slight decrease during the later phase of the flare development. The separation of the ribbons is usually stopped shortly after it's onset in complex sunspot groups. Krivsky et al. (1973) found that the separation velocity of bright ribbons equal to 50 km/sec. in the initial phase, in the case of 7 August 1972 flare but it decreased shortly to 1.3 km/sec. and the separation slowed down. Gopasyuk (1958) reported separation velocity of 100 km/sec, while Bruzek (1958) reported even higher velocity of 140 km/sec. during the first phase of the development.

In this section I have described the analysis of 30 Two Ribbon flares to investigate the following:

1) **Separation velocities of flares ribbons.**

2) **Separation velocities of flare kernels.**
3) Whether all flare kernels move or some remain stationary.

4) Does separation velocity depend on impulsive nature of flare.

5) Separation velocity in view of photospheric magnetic field.

The above studies are made in the case of spotless, and spotgroup regions:

5.1 Separation of flare ribbons in spotless regions

I have analysed 10 H-alpha two-ribbon flares which occurred in spotless regions, to determine the separation velocities in the sky plane of different H-alpha flare knots in opposite ribbons. Given in table III-4 are maximum separation velocities determined during the initial and decay phases and H-alpha rise time to see the impulsive nature of the flare. The velocities mentioned in this section refer to one ribbon or one feature only, hence the total separation velocity of two bright ribbons or two flare knots is approximately twice.

Shown in figure III-30 are line drawings of the flare events analysed for determining the separation velocity. For each event one drawing is given on which symbols are marked to show the H-alpha features and the
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<td>29 Jul.73</td>
<td>Slow</td>
<td>1.8</td>
<td>0.5</td>
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</table>
The line drawings showing separation of flare ribbons formed in spotless regions. The arrow indicates the direction of movement of flare feature. The features not shown by arrow were not moving at all.
arrow indicates the direction of motion. In figure III-31, the separation of flare ribbon features versus time is shown. The velocity refers to one ribbon or one feature.

The beginning of a subflare on 23 Dec. 1978 was missed and during the decay phase only two features were identified. The flare occurred in McMath region 15700 at S23W58 around 0520 UT. The ribbons were moving with a separation velocity of 3.5 km/sec, and thus the total separation velocity was about 7 km/sec. In the case of 12 April, 1979, each ribbon showed separating motion with a velocity of 7.5 km/sec. in the initial phase up to 0424 UT. After 0424 UT the separating velocity decreased to 2 km/sec. In the event of 16 Nov. 1980, a total separation velocity on the order of 60 km/sec. was observed between ribbons during the initial phase from 0902 to 0905 UT, but it decreased sharply to 3.0 km/sec. during the decay phase. A uniform velocity of separation of 5 km/sec, between the two flare ribbons was observed in the event of 22 Nov. 1980. In the case of 17 May 1980, the velocity of separation between the two flaring ribbons continuously decreased from 13 km/sec. in the beginning at 1012 UT to 2 km/sec. around 1025 UT. The change in velocity with the progress of the flare is also shown in the same plot (Figure III-31). The separation velocity in the case of July 29, 1973 was determined and is shown in the figure III-31. During the initial phase, the total separation
Figure III - 31. Separation velocity between two flare ribbons observed in spotless regions. Distance between the ribbons is plotted on the vertical axis and the velocities refer to the motion of one ribbon. Note different behaviour of separation of flare ribbons.
velocity between two ribbons was about 4 km/sec, which reduced to 1 km/sec. in later phase.

In 3 flares, the separation velocity of different flare kernels is also determined. Shown in figure III-32, are the separation of different H-alpha flare kernels in opposite ribbons. The separation velocity between features 2 and 3 in the flare ribbons of 25 Feb. 1979, was about 13 km/sec. in the initial phase. The feature 2 was moving in a direction such that, in the beginning it was approaching closer to feature 4 up to 0700 UT and then it moved further away. On the other hand no appreciable separation was observed between feature 2 and 5 and between 2 and 6. In the flare event of 25 March 1980, three distinct H-alpha features were identified. The feature 1 is on one ribbon and 2 and 3 were marked on the second ribbon. It was found that the ribbon 1 and the portion marked as 2 in the second ribbon were moving away with velocity of 6 km/sec. in the initial phase, while ribbon 1 and the portion marked as 3 of the second ribbon moved with separation velocity of 10 km/sec. in the initial phase. After 0437 UT, no appreciable motion was detected. The features 1 and 2 are almost in a perpendicular line, while the feature 1 and 3 are almost in a horizontal line (figure III-30). Thus the separation of ribbons were in such a way that their longitudinal distance increases more than the perpendicular distance.
A great two-ribbon flare of importance 48 was observed on 9 Dec. 1980 around 0700 UT. The features 1, 3 and 5 were identified in one ribbon and opposite to the features 2, 4 and 6 on the second ribbon, as shown in figure III-30. It is obvious from figure III-32 that the separation between each opposite pair is different. The separation between 1 and 2 was slow in the beginning, but became faster after 0737 UT. On the other hand, features 3 and 4 showed the usual trend. However, the separation between 5 and 6 was uniform. This unambiguously indicates that different portions of a ribbon move with different velocities.

In the case of TR flare 9 May 1979, no feature showed any motion of separation. Further, it is well established that flare ribbons move uniformly in spotless regions, until the flare completely decays. But in the case of spotless flare on 12 May, 1982 of which the beginning was missed, no separation was detected during the decay phase. The separation was measured at two different points in each ribbon. But both pairs (1 & 2, 3 & 4) did not show any movement. A few flares are discussed in view of magnetic field configuration in section 5.4.
Figure III - 32. Separation velocities between two kernels of opposite ribbons formed in spotless regions. Note each kernels pair moves with different velocity.
5.2 Flare ribbons in single spot regions

The separation velocities of different parts of flare ribbons were determined for 4 TR-flares, which occurred in regions with a single major spot. Various features of flare ribbons are marked on H-alpha drawings shown in figure III-33. Further, shown in figure III-34 are the separation of flare ribbons features with the progress of the flare.

The maximum total separation velocity of about 17 km/sec. was observed on 17 Dec. 1976 between features 1 and 2. During the decay phase the velocity was about 4 km/sec. It was observed that different features on flares ribbons were moving with different velocities of separation. In the case of 14 April 1977, the separation velocity of features A and B was lower in the initial phase but increased after maximum phase. On the other hand features C and D were separating uniformly. In the event of 17 Dec. 1978 features 1 and 2 are identified on one ribbon and features 3, 4 and 5 are marked on the opposite ribbon. The separation of each feature (1,2,3,4 and 5) was determined from the major spot p and it was found that from 0751 UT (beginning missed ) till the end of the flare, no feature showed any motion. It shows that in this case of TR-flare, during the decay phase no expanding motion was observed as suggested by various authors. Perhaps the separation motion stops immediately after
Fig. III - 33. Line drawings showing separation of flare kernels which formed the ribbons in single spot regions. The arrow indicates direction of movement of flare features. The features, not shown by an arrow, do not move at all.
Figure III - 34. Separation velocity between two flare kernels on opposite ribbons formed in single spot regions. Note different velocities of each pair of flare kernels on 17 Dec. 76 but almost same for each pair on 30 Dec. 76.
Figure III - 35. A diagram showing velocity of movement of each flare kernel in both flare ribbons. The distances were measured in two perpendicular directions (X & Y) from the center of the spot and plotted on vertical axis. Note that feature 3 in TR flare of 17 Dec. 76 was not moving.
reaching the maximum phase. In this case of TR-flare of 17 Dec. 1978, feature 1 was observed penetrating partially into the umbra of the spot. The flare decayed around 0817 UT. This analysis also shows that it is not necessary that all parts of a ribbon show expanding or separating motion between the ribbons. On the other hand in the case of 30 Dec. 1978 all parts in one ribbon separated at the same velocity from the opposite ribbon. As inferred from figure III-34 that the total separation velocity between features 1 and 2; 3 and 4 and 5 and 6 is almost 6 km/sec. in the initial phase and about 2 km/sec. during the decaying phase.

On considering the center of the spot as the origin of two axis and point of reference, I determined the velocity components in the sky plane of each feature, in the event of 17 Dec. 1976 to determine the dominant direction of motion. Shown in figure III-35 are the separation of different features from the spot centre as origin of the X-Y axes. This study showed that feature 3 was neither moving in X-axis nor in Y-axis. A similar study was made for the TR-flare of April 14, 1977, revealed that features B and C were not moving at all.

5.3 Separation of Ribbons in complex spots regions

The study of separation velocities of flare ribbons and flare features is made for 16 flares, occurred
complex sunspot groups. In figure III-36, H-alpha drawings, of these flares are shown together with notations of different flare features. Shown in figure III-37 are the separations of different flare features in opposite ribbons.

The TR-subflare of 29 Dec. 1976, show slow separation motion during the initial phase. The total separation velocity of ribbons during the initial phase was about 7 km/sec. On the other hand, in the case of great two-ribbon flare of 30 Dec. 1976 occurred in the same region (where SB flare of 29 Dec. 1976 occurred), all parts of one ribbon separated from the opposite ribbon, with the same velocity. The total velocity of separation was about 18 km/sec, in the initial phase and 3.5 km/sec, during decay phase. In the case of 2 Feb. 1979 (beginning missed), a uniform separation velocity of 1 km/sec, was observed during the decay phase.

In the case of 22 May 1979 flare (figure III-36) features 1 and 4 formed one ribbon of the TR-flare and features 2 and 3 formed the second ribbon. Both flare kernels 2 and 3 were moving with the same separation velocity of about 2 km/sec, with respect to opposite flare kernel, 1 in the beginning. In TR-flare occurred at 0740 UT on 6 Oct. 1979, it was found that a single big flare ribbon bifurcated into two ribbons around
Figure. III - 36. Line drawing of flare ribbons showing separation in complex spot groups. The arrow indicates direction of motion.
Figure III - 37. Separation velocities of two flare kernels on opposite ribbons formed in complex spot groups. Note that in some TR flares, pairs of opposite features have same separation velocity while in many cases they do not have same velocity of separation.
0743 UT. The total velocity of separation between 1 and 2 was about 20 km/sec. The separation was in North-South direction. The separation between 2 and 4 was determined but the feature 4 hit the spot $f_1$ and thus no motion was seen after 0747 UT. In the beginning the separation velocity measured between the two flare kernels 1 and 2 in opposite ribbons of 9 Oct. 1979 flare event was about 4 km/sec, which increased to 7 km/sec. after elapse of 20 minutes from the flare start. In the case of 9 Nov. 1979 TR-flare, three successive TR-flares occurred in the same region and almost at the same location (homologous flares, cf section 2.3.2). During the initial phases a separation velocity between the two opposite ribbons (1 and 2) was observed as 8 km/sec. in the case of first flare at 0310 UT, about 15 km/sec in the case of second flare at 0547 UT and 27 km/sec. in third flare, which occurred at 0603 UT. The separation velocity during the decaying phase was almost the same ($\approx$ 3 km/sec.) in the case of first and the second flare, but it was about 7 km/sec. in the third flare. The observed increase in separation velocity from one to another flare could be due to progressive increase in the energy of the flare or decrease of magnetic field (breaking force) in the region with time. However, the first possibility is confirmed as, the second flare was more impulsive than the first and the third was the most impulsive. This flare is discussed in view of magnetic field in next section.
In the case of flare of 3 April 1980, many flare kernels were identified in the two opposite ribbons. The separations of various flare kernels in the second ribbon from the flare kernel 1 in the first ribbon, were determined, and is shown in figure III-37. In this flare event, the feature 5 did not show motion. The maximum velocity of separation was determined for feature 1, which was moving with almost 25 km/sec.

The beginning of the flare, on 16 April 1980, (figure III-37) was missed. The feature 1 and 3 are marked on one ribbon and 2 on the second ribbon. The initial separation velocity between the ribbons was quite appreciable (~8 and 14 km/sec.). In the case of flare of 17 April 1980, it was found that the ribbons were not separating at all. However, a flare kernel 4, which perhaps was an independent brightening, was observed to move away from both ribbons (features 1 and 3) with a velocity of about 6-7 km/sec. On 20 Feb. 1981 (figure II-37) two flares occurred around 0545 UT and 0640 UT in the same region but at different locations. Both flares were impulsive, the separation velocity between the two ribbons 1 and 2 was about 17 km/sec. in the initial phase of both flares. However, the separation velocity during the decay phase was only 1 km/sec. in first flare while it was about 4 km/sec. in the case of second flare. A great 3B importance flare occurred on
13 May 1981 (figure III-36) of which the beginning and maximum, both were missed and thus the separation shown in the figure III-37, between features of opposite ribbons refer to the decay phase only. The separation velocity was about 1-2 km/sec, between the flare kernels of opposite ribbons. In the case of flare of 29 May 1981, (Figure III-37) only one ribbon marked as 1, showed motion and the second ribbon marked as 2 and 3 did not show motion at all.

To see that whether the whole flare ribbon moves or only some portion of it moves or does not move at all, I have determined the distance of different part of the flare ribbons from the sunspots (considering the spots had no appreciable motion during flare activity). This study is made for 10 flares. Further for 3 events, this study was made in two X and Y axes. The velocities of different flare ribbon kernels are shown in figure III-38 a and b.

This study revealed that in some flares both ribbons move away from each other, while in other flares, only some portion show motion. However, sometimes ribbons do not show any motion at all. In general the separation velocity during the initial phase remains higher, but in a few cases it remains uniform. In a few events it was observed that the separation velocity was less in beginning phase as compared to the decaying phase.
Figure III - 38(e) The distance of each flare kernel in both ribbons measured from one spot in complex sunspot groups and plotted on vertical axis. Note that some features in the ribbons do not move at all.
Figure III-38(b) The drawing showing the distances measured in two perpendicular directions (X & Y) from the center of the spot and plotted on the.
The impulsive flares showed higher initial separation velocity.

5.4 Separation of flare ribbons in relation to photospheric magnetic field

The magnetic field observations of the regions which produced TR flares analysed in this thesis, were not available during flare activity. Thus I used photospheric magnetic fields maps obtained at Mt. Wilson Observatory about 12 hours earlier or later to indicate approximate location of sunspot and flare ribbons. The drawings of sunspots and flare-ribbons on magnetogram are shown and discussed in section 2. The separation of flare ribbons depends on the magnetic field configuration in the region. A study of 12 Two-Ribbon flares show that in most of the cases the velocity of separation of ribbons during the rising phase of the flare remains higher because the strength of magnetic field \( H_{\parallel} \) at the location of flare occurrence (in proximity of \( H_{\parallel} = 0 \) line) was of smaller strength. The separation velocity of each ribbon or each flare feature in the beginning, when it travelled along field of 5 - 10 gauss, was ranging between 7 to 15 km/sec. and upto 7 km/sec. in the field of 10 -20 gauss.

In the case of impulsive flares, higher initial separation velocities were generally observed. If a flare is impulsive and if it occurs in a region of simple
magnetic field configuration, it shows higher initial velocity of separation. Further, in such impulsive flares, after the explosive phase, a sudden decrease in separation velocity occurs and could be of the order of 1-3 km/sec.

In the case of 9 Nov. 1979 homologous TR-flares in which these flares occurred at the same location, separation velocities of the last flares was higher, the magnetic field configuration was almost same, but the last flare was impulsive and of higher importance class too, therefore higher separation velocities were observed.

The magnetic field configuration in the region of 9 May 1979 flare was quite simple, neither reversed polarity nor intermingle of fields were present. In this case no motion of any feature was observed. Those TR flares which showed separation of ribbons and filament motion, seems to occur in regions which have reversed and mixed polarities.

In the case of 17 April 1980, in which only one feature 4 (Figure III-36) was found to move, which appeared in the positive polarity region of moderate strength. The other features formed in strong fields of negative polarity did not show any motion.
6.0 **Growth of H-alpha loops**

The Two-Ribbon flares that form in a well developed active regions often accompany a phenomenon called arcade of loops. On rare occasions this loop system has been also observed associated with spotless twibbon flares. Around the flare maximum the flare material appears streaming downward along both legs of the bright loops. The system of loops continues to grow at a steadily reduced rate up to a height of 60,000 km or more and it may last for ten or more hours after the flare decays. Usually, in the H-alpha line, it is difficult to see the loops on the disc, but in some outstanding cases they form an arcade bridging the neutral line ($H_{\parallel} = 0$) and connecting region of opposite magnetic polarities (Bruzek 1969 b). Out of 30 TR-flares only in 10 flares the H$_x$ – loop structure was observed. I give in this section the growth of H-alpha loops for 3 TR flares measured in the sky plane. Given in table III-5 are date of flare events, position on the disk, maximum height (elongation) and maximum velocity of the loop. The growth of the loops (height v/s time) is shown in figure III-39.

The growth of the loop system is due to generation of new higher and higher loops while the smaller ones fade out. The lifetime of a single loop is about 20 min. (Bruzek, 1969b). Each individual loop starts as a rapid
### TABLE III-5 MAXIMUM HEIGHT AND MAXIMUM VELOCITY OF THE TR-FLARE LOOPS

<table>
<thead>
<tr>
<th>Date</th>
<th>Flare location</th>
<th>Region type</th>
<th>Max(^{\text{m}}) height (\times 10^3) km</th>
<th>Max(^{\text{m}}) Velocity km/sec</th>
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</thead>
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<tr>
<td>12 Apr. 79</td>
<td>N12W05</td>
<td>Spotless</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>9 Nov. 79</td>
<td>S15W02</td>
<td>Spotgroup</td>
<td>23</td>
<td>9</td>
</tr>
<tr>
<td>29 May 81</td>
<td>N18W38</td>
<td>Spotgroup</td>
<td>86</td>
<td>17</td>
</tr>
</tbody>
</table>
Figure III-39: Growth of Hα-flare loops seen in the sky plane. Height of loops is plotted on the vertical axis.
brightening of a knot at the top of existing loops; the knot grows for several minutes and eventually it flows downward along the magnetic field lines. I have determined in the sky plane, velocity of the bright knots flowing downwards along the loop (magnetic field lines) in the case of 13 May 1981 and shown in figure III-40. Near the top of the loop the bright knot shows maximum downward velocity, but the velocity decreases as it approaches towards the feet of the loop (chromosphere). Thus bright knots decelerates towards higher magnetic fields.

In the beginning, the bright H-alpha loops show higher velocity of growth, but as the flare decays their growth rate also reduces. The growth of flare loops follow the same trend and velocity, as the separation of flare ribbons which lie at the feet of these flare loops. The arcade structure of the loops, perhaps indicates that the flare energy stored in the magnetic field prior to the flare occurrence, had to be almost completely released during the flare phenomenon. The good examples in support of this idea are flares of 17 May 1980 and 12 April 1979 in which one ribbon is under formation, while the other appears when the material flows down through the loop (cf section 2). This suggests that the loops are being created prior to the flare onset but not visible in Hα line center in the most of cases. However, if we imagine that loops are being formed prior to the flare onset then we should also imagine a sudden reconnection
Figure III - 40. Deceleration of material motion seen along the post flare loops observed in TR flare of May 13, 1981. Note that velocity decreases as the material approaches towards feet of the loops.
in the open field lines to form the loops. Thus, the observations show that rapid reconnection starts prior to or at least at flare onset and thus giving more number of loops (arcade) in the beginning (growth rate is higher in the beginning). The rate of reconnection decreases as the flare maximum passes away (figure III-40) and thus the growth rate of loops decreases as well as the area and intensity of flare. In other words the rapid reconnection at the time of flare beginning, provides higher energy to account for the intense brightness of the flare ribbons.

7.0 Estimation of H-alpha energy in TR-flares and non-TR-flares

The estimation of the total energy radiated in H-alpha can be made in more than one way. Thomas (1970) proposed an accurate method of determining the energy by photometry of the whole flare area according to the following formula.

\[ \Delta E_{H\alpha} = 7.9 \times 10^{33} \bar{A} (3.1 \frac{Po(H\alpha)}{Po(c)} - 1) \text{ ergs/sec.} \]

where \( \bar{A} \) is the area in steradians,
\( \frac{Po(H\alpha)}{Po(c)} \) is the value of the peak intensity with respect to the continuum at the disk centre.
The flare surface energy can be determined using the IAU definition for the individual importance.

\[ \Delta H_{\alpha} = \frac{1}{3} \Delta E_{H_{\alpha}} \]

Thus the total energy radiated in H-alpha is

\[ E_{H_{\alpha}} = \frac{1}{3} \Delta E_{H_{\alpha}} \times t \quad \text{ergs} \]

where \( t \) is duration of the flare in seconds.

I have determined \( E_{H_{\alpha}} \) for 6 flares using the values \( P_{o}(H_{\alpha}) \) as used by Pinter (1970) for the individual importance. The various parameters are given in table III-6.

It seems that a TR flare releases more energy as compared to a non-TR flare of the same importance class. To obtain some idea of how many times TR flares emit more energy than N-flares, I made an empirical estimation of the energy generation in H-alpha using Obashev's method (1968). According to Obashev, the total flare energy in H-alpha is expressed by

\[ E_{H_{\alpha}} = 2.5 \times 10^{23} \alpha U T^{5/2} \quad \text{ergs} \]

Where \( U \) is the energy radiated from the flaring region per unit volume per unit time in H-alpha;
\( \chi \) is the transformation coefficient \((0.75 < \chi < 1)\)

\( T \) is overall period of the flare in seconds.

If the average energy \( U = 0.02 \text{ erg/cm}^3/\text{sec.} \) and \( \chi = 0.80 \)
then above relation transforms to

\[
E_{\frac{H}{\chi}} = 4.0 \times 10^{21} \cdot T^{5/2} \quad \text{ergs.}
\]

This shows that \( E_{\frac{H}{\chi}} \) depends on the overall period of the flare. Thus accuracy of time measurement is required.

I have determined mean, \( (\bar{T}) \), median \( (T_M) \) and modal \( (T_{MO}) \) values of \( T \) for Normal (Non-Two Ribbon) and Two Ribbon flares of different importance class during the period 1976-1980. The list of the months for which data used from S & G reports is given in Chapter IV.

Using mean, median and modal values of \( T \) for TR and N flares; the mean, median and modal energy values in H-alpha for different importance class flares determined and given in table III-7.

This statistical analysis shows that for flares of importance 1, the ratio of the TR and N flares, mean energy is
for flares of importance 2,

\[ \frac{E_{H\alpha}^{(TR)}}{E_{H\alpha}^{(N)}} = \frac{3.1}{1.4} = 2.2 \]

and for flares of importance 3,

\[ \frac{E_{H\alpha}^{(TR)}}{E_{H\alpha}^{(N)}} = \frac{9.4}{5.7} = 1.6 \]

This implies that TR flares emit more energy as compared to N-flares. Further class 1 and class 3 TR flares have almost 2 and 8 times respectively higher energy than N-flares of the same importance class, while the class 2 TR flares do not show significant higher energy (\( \leq 1.6 \)) in comparison to N flares of class 2 importance. If this is true then it gives an idea that TR-flares of importance 1 should emit higher energy at other wavelengths also as compared to N-flares of same importance class.

Further, the flare associated phenomena at different wavelengths should be significantly higher in case of class 1 TR flares as compared to N-flares. Similarly, class 3 TR flares should show the highest correlation with different wavelengths phenomena. However, class 2, TR-flares and N-flares, may give no comparable flare associated phenomena.
I have examined and described in the following chapters such correlations for TR and N-flares, with different flare associated phenomena. The above results further support the findings presented in the subsequent chapters V, VI and VII.
<table>
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<tr>
<th>Date</th>
<th>Importance</th>
<th>$\frac{\Delta}{\Delta}$</th>
<th>$P_c(H\alpha)$</th>
<th>$\frac{1}{3} E_{H\alpha}$</th>
<th>Duration (secs.)</th>
<th>Total energy $E(H\alpha)$ (ergs)</th>
</tr>
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<td>2B</td>
<td>$3.6 \times 10^{-8}$</td>
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<td>4610</td>
<td>$1.6 \times 10^{30}$</td>
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<td>660</td>
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