DEVELOPMENT OF A COMPLEX OF ACTIVITY IN THE SOLAR CORONA

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Abstract. Skylab observations of the Sun in soft X-rays gave us the first possibility to study the development of a complex of activity in the solar corona during its whole lifetime of seven solar rotations. The basic components of the activity complex were permanently interconnected (including across the equator) through sets of magnetic field lines, which suggests similar connections also below the photosphere. However, the visibility of individual loops in these connections was greatly variable and typically shorter than one day. Each brightening of a coronal loop in X-rays seems to be related to a variation in the photospheric magnetic field near its footpoint. Only loops (rarely visible) connecting active regions with remnants of old fields can be seen in about the same shape for many days. The interconnecting X-ray loops do not connect sunspots.

We point out several examples of possible reconnections of magnetic field lines, giving rise to the onset of the visibility or, more likely, to sudden enhancements of the loop emission. In one case a new system of loops brightened in X-rays, while the field lines definitely could not have reconnected. Some striking brightenings show association with flares, but the flare occurrence and the loop brightening seem to be two independent consequences of a common triggering action: emergence of new magnetic flux. In old active regions, growing and/or brightened X-ray loops can be seen quite often without any associated flare; thus, the absence of any flaring in the chromosphere does not necessarily mean that the overlying coronal active region is quiet and inactive.

We further discuss the birth of the interconnecting loops, their lifetime, altitude, variability in shape in relation to the photospheric magnetic field, the similarity of interconnecting and internal loops in the late stages of active regions, phases of development of an active region as manifested in the corona, the remarkably linear boundary of the X-ray emission after the major flare of 29 July 1973, and a striking sudden change in the large-scale pattern of unipolar fields to the north of the activity complex.

The final decay of the complex of activity was accompanied by the penetration of a coronal hole into the region where the complex existed before.

1. Introduction

In 1965, Bumba and Howard defined a complex of activity in the photosphere as a cluster of newly born active regions which expands for several rotations both in latitude and longitude and finally disintegrates in the ambient old fields. The authors listed five examples of the behavior of photospheric magnetic fields in such clusters which were recognizable on the Sun for 4 to 8 rotations. The individual active regions in such a complex of activity may have some common characteristics, e.g., an increased rate of particle production, as was demonstrated by Švestka (1968) and Gros *et al.* (1971).

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Table I
List of active regions which developed in the activity complex

AR No.	McM No./rotation	First seen	Longitude	Latitude	Sunspot area
C1	12375/1602	4 June	262°	13N	170
	417/1603	29 June	267°	13N	520
	461/1604	26 July	272°	13N	0
	497/1605	22 Aug.	274°	13N	0
	533/1606	19 Sept.	281°	16N	0
	576/1607	16 Oct.	287°	9N	0
C2	378/1602	6 June	279°	7N	0
C3	381/1602	7 June	289°	14N	0[a]
C4	414/1603	28 June	278°	7S	140
	460/1604	25 July	289°	6S	120
	495/1605	21 Aug.	295°	6S	0
C5	420/1603	2 July	242°	15N	0[a]
C6	426/1603	6 July	278°	1N	0[a]
C7	427/1603	5 July	249°	2N	100
	— /1604	28 July	258°	0	0
C8	430/1603	8 July	261°	1N	0[a]
C9	471/1604	1 Aug.	240°	15N	10
	501/1605	23 Aug.	252°	15N	140
	535/1606	20 Sept.	252°	14N	450
	577/1607	17 Oct.	255°	15N	30
	623/1608	16 Nov.	251°	15N	0
C10	473/1604	2 Aug.	276°	3S	0
C11	500/1605	23 Aug.	264°	22N	0
C12	503/1605	25 Aug.	268°	3N	100
	530/1606	18 Sept.	282°	5N	20
	576/1607	16 Oct.	287°	9N	0
C13	504/1605	25 Aug.	226°	12N	0
	536/1606	22 Sept.	234°	10N	0
C14	505/1605	28 Aug.	237°	2N	0[a]
C15	509/1605	29 Aug.	244°	12S	100
	534/1606	20 Sept.	251°	14S	0
	578/1607	18 Oct.	253°	15S	0
C16	511/1605	31 Aug.	252°	5N	30
	532/1606	19 Sept.	258°	7N	160
C17	538/1606	25 Sept.	261°	29S	0[a]
C18	618/1608	12 Nov.	268°	14N	100
	656/1609	12 Dec.	278°	16N	0
C19	629/1608	22 Nov.	267°	8N	0[a]
C20	658/1609	12 Dec.	272°	11S	0[a]

[a] Died on the disk.

One clearly defined complex of activity was born, developed, and decayed during the Skylab mission. We thus had a unique opportunity to see the development of such a cluster of active regions in the solar corona, by using the soft X-ray photographs of the Sun obtained by the AS&E S-054 ATM experiment on Skylab. This paper discusses the observational results we have obtained from a study of these data. Detailed interpretation will be carried out in later papers (Švestka, 1977 is one of them).

2. Development of the Activity Complex

The complex of activity we discuss was born in rotation No. 1602 with the birth of the active region McMath 12375, which was first seen on 4 June 1973. During its life, for 8 rotations, the complex developed 20 different individually numbered active regions. We will number them C1 to C20, and the key to this numbering is given in Table I. Many of them were short-lived, but nine of them lived for more than one rotation. The positions and developments of these nine regions are shown schematically in Figure 1.

As usual (Bumba and Howard, 1965), the region that occurred first (McMath 12375, our number C1) had the longest lifetime, staying on the Sun for 6 subsequent rotations. In rotation No. 1607 it merged with region C12 (originally McM 12305 in rotation No. 1605) and decayed behind the limb. But in the meantime another region, C18 (McM 12618), formed close to the original position of C1 in rotation No. 1608. Such a persistence of activity, too, is typical

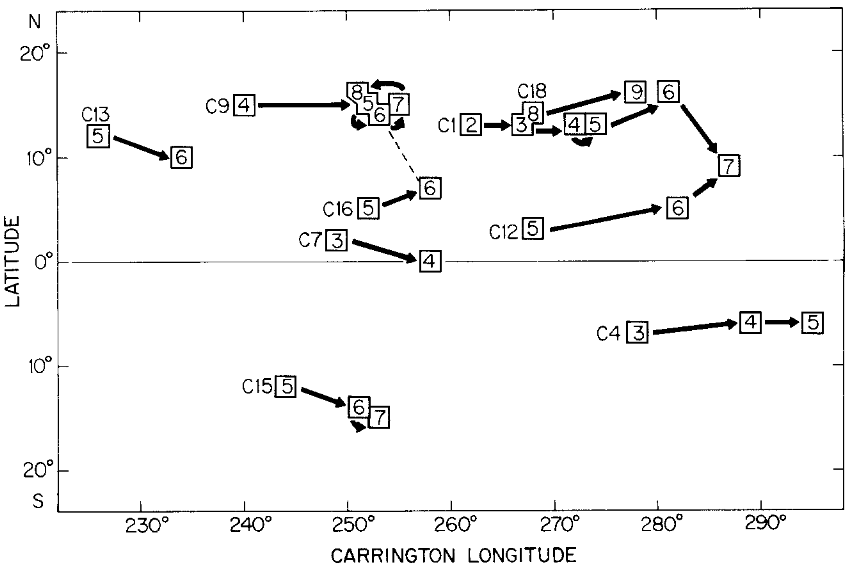


Fig. 1. Identification chart for the nine recurrent active regions in the complex of activity. Squares show their positions (number 5 inside a square means position in rotation No. 1605) and arrows indicate the positional shift between subsequent rotation. C12 means active region No. 12 in Table I.

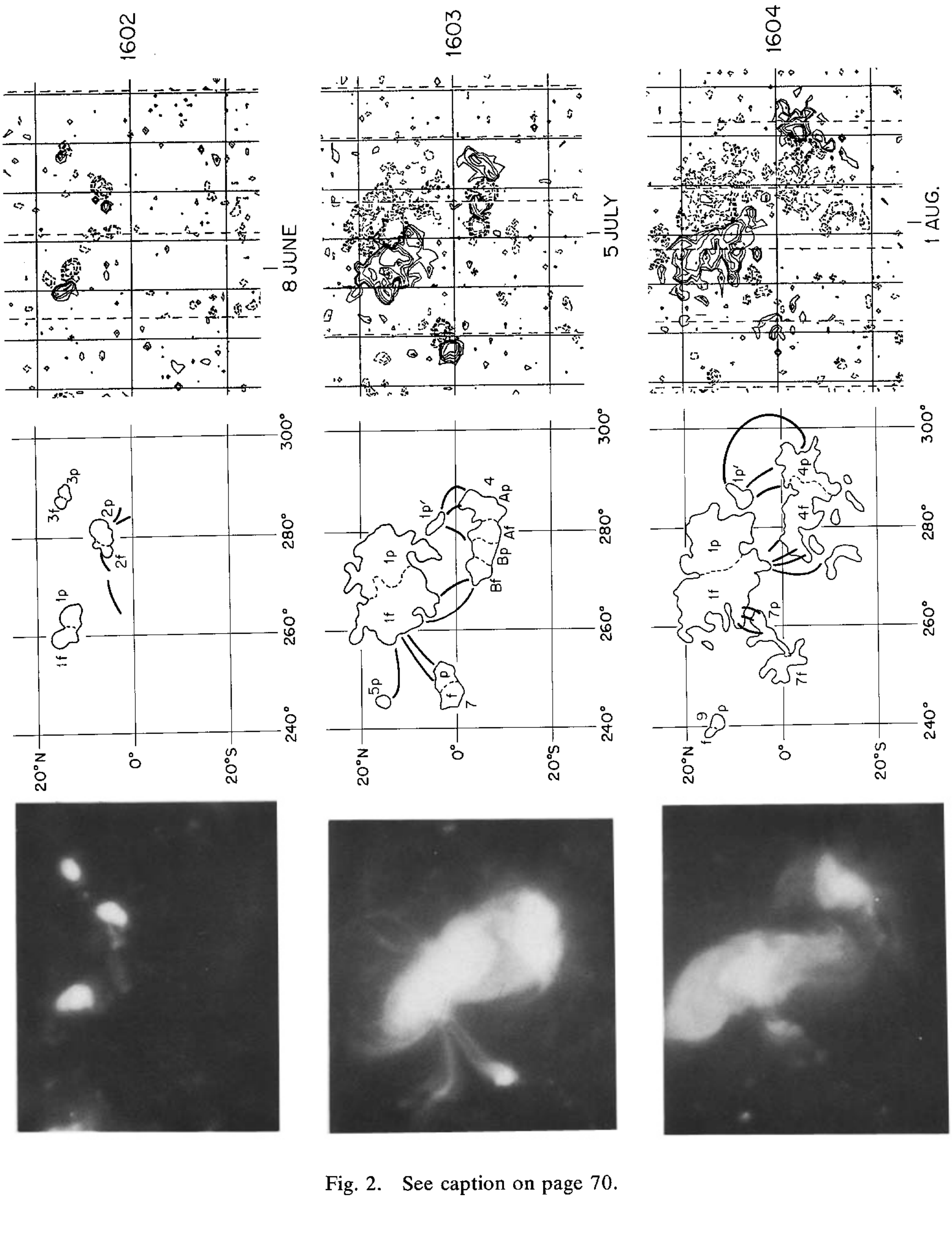
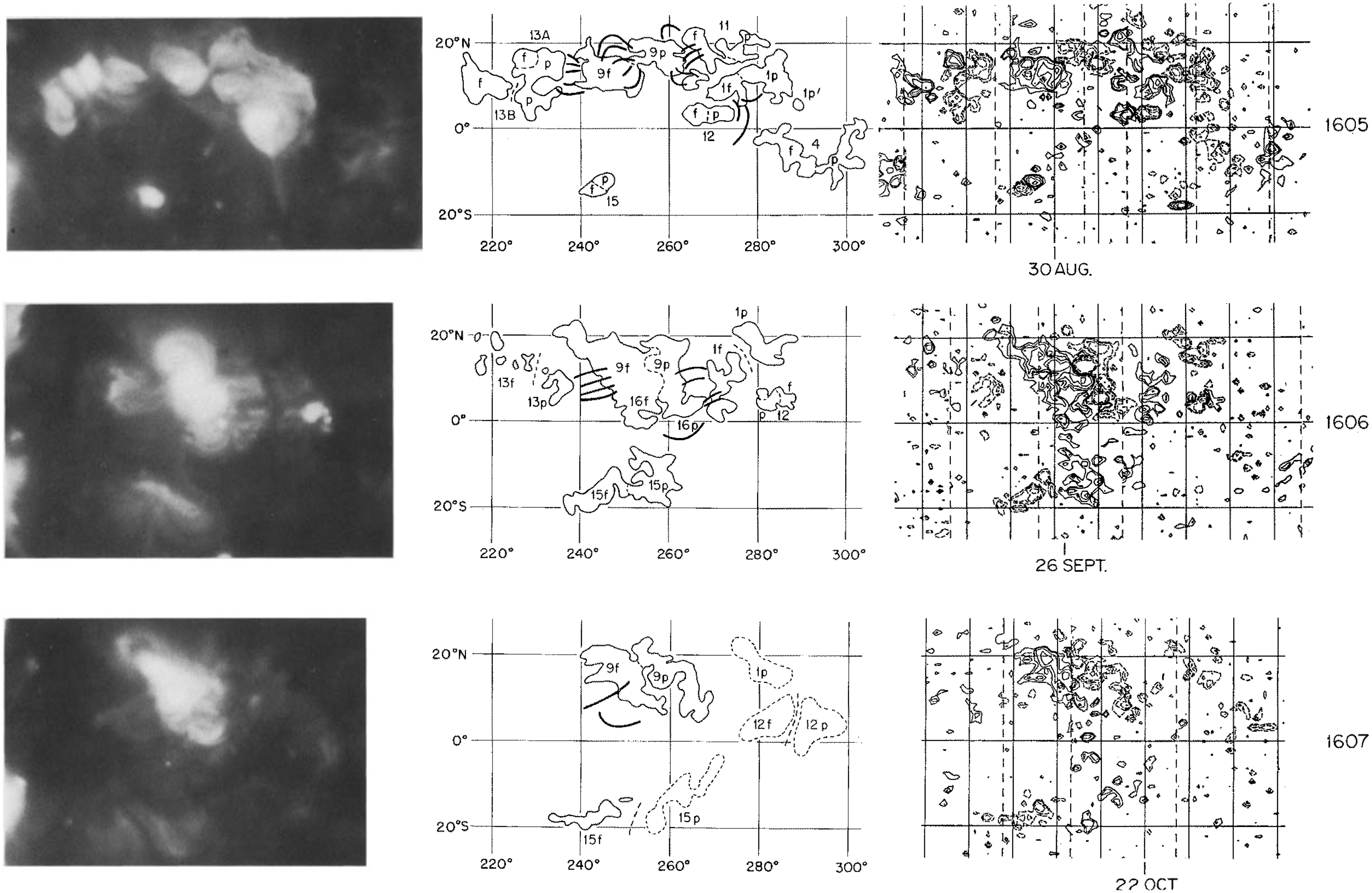


Fig. 2. See caption on page 70.


1605
1606
1607
30 AUG.
26 SEPT.
22 OCT
20°N
0°
20°S
220°
240°
260°
280°
300°
13A
13B
9p
9f
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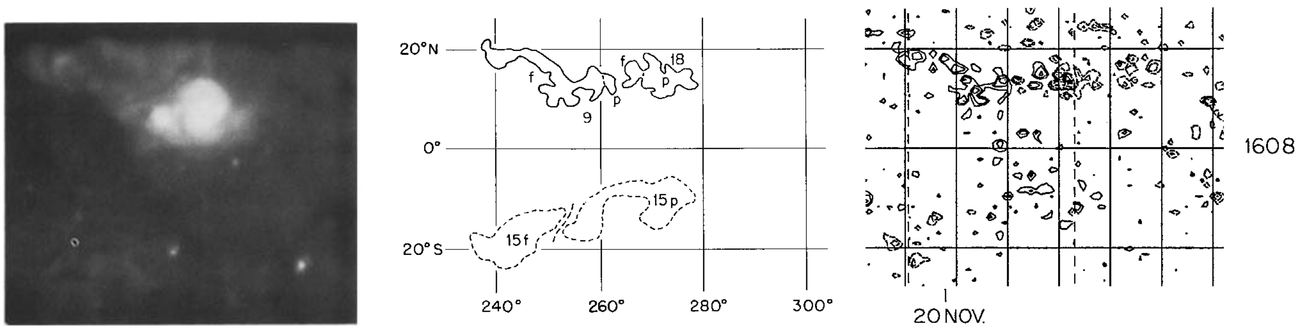


Fig. 2. Characteristic features of the activity complex in each rotation. Mt. Wilson synoptic magnetic maps are on the right and soft X-ray photographs for near the time of the central meridian passage of the complex are on the left. The X-ray pictures are photographs through a passband of 2 to 32 Å and 44 to 54 Å, with 16 s exposure time. In the central column we give schematic contours of the magnetic field with numbering of active regions according to Table I, 'p' means the preceding, and 'f' the following, polarity. We also indicate here the brightest and longest-lived interconnecting loops. West is to the right.

for complexes of activity (Švestka, 1968). This new region disappeared after two rotations and the whole complex can be considered decayed in rotation No. 1610.

In rotations 1603 to 1605, the backbone of the activity complex was formed by regions C1 (at 13° N) and C4 (McMath 12414 in rotation No. 1603, at 7° S). Later, the activity shifted more to the east, being carried mainly by regions C9 (McMath 12471 in rotation 1604, at 15° N) and C15 (McMath 12509 in rotation 1605, at 14° S). The large-scale development, in photospheric magnetic fields and in soft X-rays, is demonstrated in Figure 2 and we shall now discuss all the interesting features we have seen in this complex.

3. Rotations 1601 and 1602

In rotation 1601 the Sun was completely inactive between 210° and 300° longitude, where our complex of activity began to develop one rotation later (cf. NOAA, 1973). The background magnetic-field pattern in that area consisted of a large negative Unipolar Magnetic Region in the southern latitude poleward of 20°. This feature extended almost completely around the Sun at the higher southern latitudes and constituted one of the most striking weak magnetic regions in recent years. In the longitude zone where the complex of activity started, the UMR reached nearest to the equator. At the equatorial and northern latitudes in this longitude zone there were three weak unipolar areas. The strongest was a positive region in the east, west of that was a weak negative region, and west of that was a weak positive region. This configuration may be seen in the Mount Wilson magnetic synoptic charts, published in the *IAU Quarterly Bulletin on Solar Activity*, No. 182.

Region C1 (the first and basic component of the complex) was first seen in the photospheric magnetic field and in the Ca II filtergrams on 4 June, at 65° E. Unfortunately, there was a gap in Skylab data at that time so that the first soft X-ray data from the S-054 experiment are available only on 8 June. At that time region C1 was joined by two other regions C2 and C3 (cf. Figure 2 and Table I), all in the northern hemisphere. Region C1 remained quite small throughout most of this first disk passage. Region C2, which was born on June 6 and grew fast on June 6/7, developed a system of loops extending eastward. But these loops never actually reached C1, and ended instead in small magnetic features located to the west and to the south of C1. Region C2 died behind the west limb. Region C3 was inconspicuous and lived for only 5 days. Only region C1 produced flares, particularly after June 11 when it began a rapid growth. Two of the subflares on June 14 and 15, when C1 was near the west limb, might have been associated with weak microwave bursts, but generally the region produced only 'quasi-thermal' flares (5 of them) and subflares (32 of them). Generally, the newly born complex of activity was a rather uninteresting feature on the Sun during its first rotation.

4. Rotation 1603

Region C1 must have continued its fast growth on the invisible hemisphere, since it emerged at the east limb as a large, fully developed active region with an extensive sunspot group (Mt. Wilson No. 19219, area 400–500 mil. of hem.) and intense radio flux (10 to 15 units at 9.1 cm) (NOAA, 1973). The sunspot magnetic configuration alternated between βp and $\beta\gamma$, and the region reached the maximum phase of its development around July 8 or 9.

During the invisible period on the other side of the solar disk another extensive region, C4, was born in the southern hemisphere. During June 30/July 1 new flux emerged at the eastern periphery of C4, making it actually a double region, as one can see in Figure 2. We will denote its components C4A (preceding part-p and following part-f) and C4B (p and f). Portion A is the older one, located more to the west. C1p, C4Af, and C4Bf are of negative (southern) while C1f, C4Ap, and C4Bp are of positive (northern) magnetic polarity.

4.1. Altitude of interconnecting loops

When regions C1 and C4A emerged from behind the east limb, a number of loops emanating from these regions could be seen off the limb (Figure 3a). These loops generally appeared more straight than the beautifully curved loops seen against the disk. The reason for this may be that off the disk we see sometimes only the lower portions of higher loops, and two of them may be in projection erroneously interpreted as one loop. Some of these loops still may connect from one region to the other, but the effects of projection at that location make it difficult to be certain of this. Quite definitely two loops were visible in projection on the disk one and two days later (Figure 3b) but these loops seemed to be low-lying and not identical with the high loops on the limb.

One must realize that it is difficult to distinguish low-lying loops (at $\leq$25 000 km altitude) on the limb, due to the bright diffuse X-ray solar limb; on the other hand, high loops cease to be distinguishable as soon as they are projected on the disk. Thus, Figure 3b shows clearly that regions C1 and C4A were interconnected across the equator with a system of low-flying loops emitting in soft X-rays; moreover Figure 3a suggests that also much higher interconnections might have existed in the corona.

4.2 Reconnection of newly emerging flux

The low-lying loops in Figure 3b connect both the preceding and following fields in C1 and C4A. Late on July 1 and on July 2, however, this situation changed: the preceding loop no longer appears to connect to C1, but now is rooted in an isolated negative feature C1p′, SW of C1, while the following loop apparently shifted from C4Af to C4Bf (cf. Figures 2 and 3m for these notations). On 2 July also a new, very bright loop formed from C1p′ to C4Bp (cf. arrow), as one can see in Figure 3c. The connection of C1p′ with C4Ap did not disappear entirely, but it became much weaker than that with C4Bp. Thus, *within about one day after its emergence, the new field C4B became connected through a brightened loop with the existing field structure* and captured much of the visible connection with C1 from the older C4A.

Note that the connection to C1p′ implies that *the X-ray loop we see does not connect to a sunspot.* A similar observation was made for another transequatorial loop, which we described in our earlier paper (Švestka *et al.*, 1977).

As with the case we studied earlier (Švestka *et al.*, 1977), it is difficult to say whether the loop brightening was, or was not, associated with a flare. The bright X-ray loop between C1p′ and C4Bp, demonstrated in Figure 3c, was seen at 13^h30^m, whereas it was absent 16 hours earlier and 8 hours later. Thus it was a transient phenomenon, with lifetime shorter than one day. Solrad-9 (NOAA, 1973) measured at about the same time a long-lived X-ray enhancement which set in at 13^h20^m, reached maximum around 14^h20^m and after that slowly decayed for several hours. One can suppose that this reflects the time development of the loop shown in Figure 3c. Observatories at Arcetri and Locarno reported a strange weak (Sf) Hα brightening at 12^h30^m which reached maximum at 15^h38^m and decayed at about 16^h. Three groups of type III radio bursts (but no microwaves) were also recorded from 13^h58^m to 15^h21^m. However, we cannot see any X-ray flare in C4Bp on Figure 3c taken at 13^h33^m when the Hα subflare should have been in progress. Thus it seems more likely that the brightened X-ray loop produced the Hα brightening rather than vice versa.

In our earlier paper (Švestka *et al.*, 1977), we arrived at the conclusion that the flare occurrence and the loop brightening are two different consequences of the same agent, namely, newly emerging flux. Thus they are not independent, but neither does one necessarily cause the other. The same may be the case here. The bright transients in loops are observed when the magnetic field in one of the foot-points rapidly increases; such an increase usually also produces a flare.

The fast appearance of a visible connection of the newly emerged field C4Bp with C1p′ is a tempting example of a magnetic field reconnection: a portion of the field lines between C1p′ and C4Ap moved to and reconnected with C4Bp. However, as we point out for another case in Section 6.2, one can never be absolutely certain that the field did not exist before and simply strengthened as the new flux emerged in its vicinity.

4.3. Growing loops in C1

In the evening hours of 2 July the whole situation changed, because region C1 developed extensive internal loops which overlay region C4B, being rooted in C1p and C1f (Figure 3d). One possibility is that these loops developed by the reconnection of some of the loops from C1f to C4Bf and C4Bp to C1p′, that can be seen in Figures 3b and 3c. Of course, it is equally possible that these loops existed before and became visible through an increase in temperature and/or density. Finally these loops might have been born in a subflare which occurred in

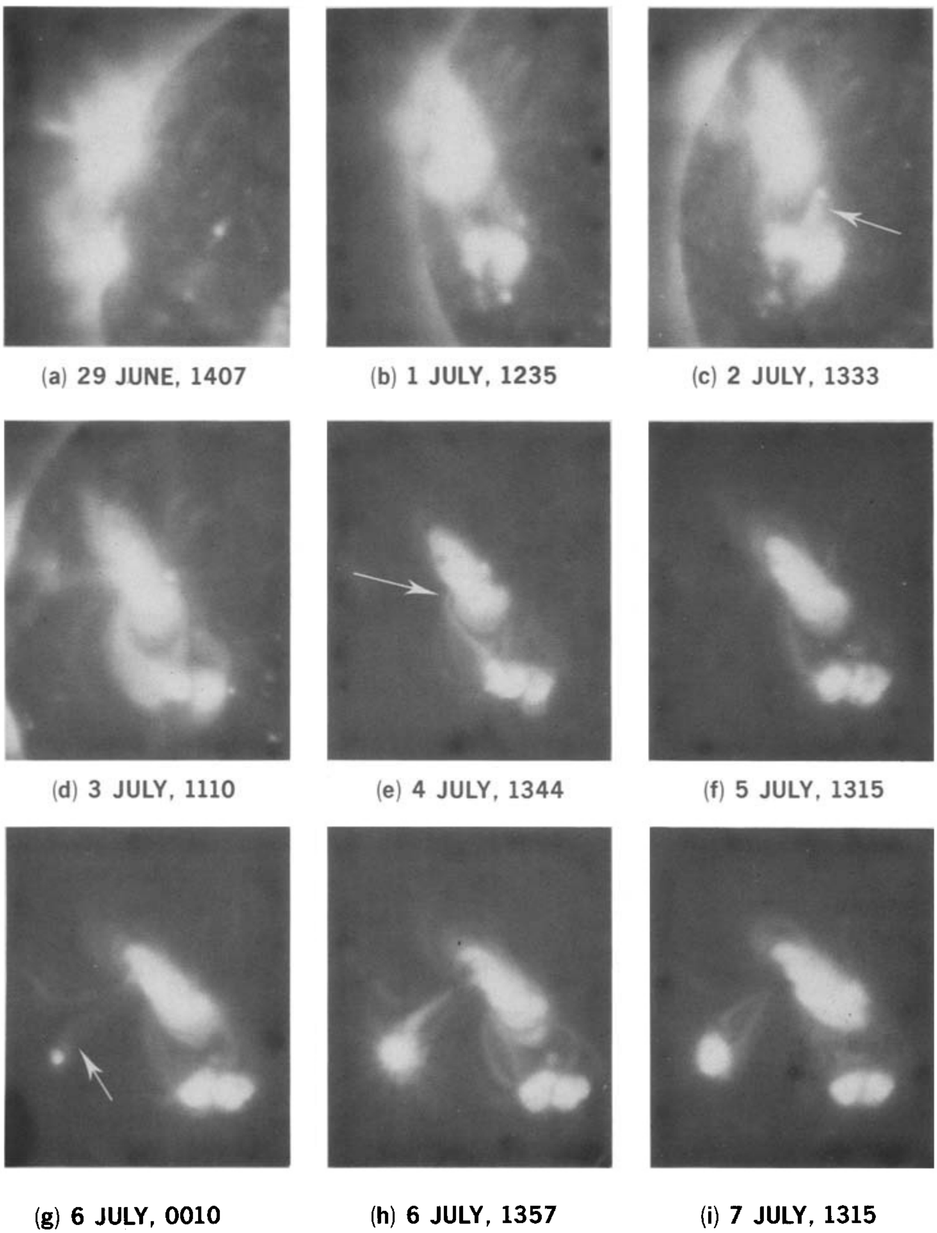
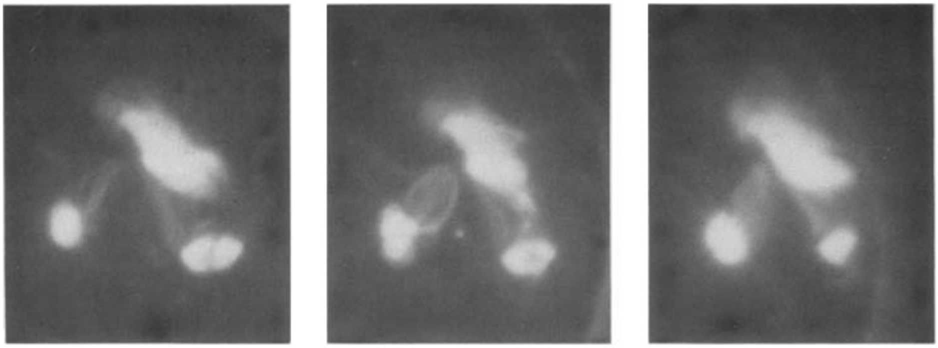
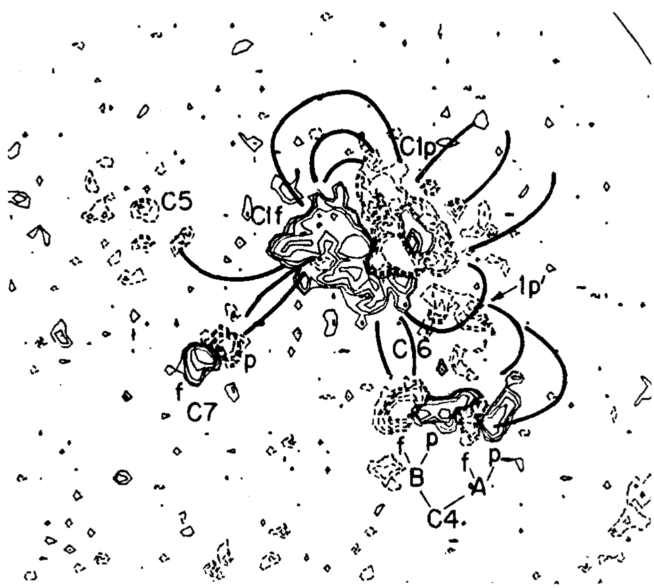


Fig. 3. The development of the complex of activity as seen in soft X-rays during rotation No. 1603. Pictures (a) to (d) were taken with an exposure time of 64 s, the remaining ones with an exposure of 16 s. All photographs were obtained through filter 3 which has a passband of 2–32 Å and 44–54 Å. Figure (m) shows the most important loop connections projected upon the Mt. Wilson magnetic field map.



(j) 7 JULY, 1959 (k) 8 JULY, 1407 (l) 9 JULY, 1324



(m)

C1 at 7^h53^m UT on July 1, and expanded until they reached a (projected) distance of 240 000 km from the original flare site (Figure 3d). In that case the X-ray loops would have grown with a (projected) mean speed of $1.3\ \mathrm{km\ s^{-1}}$. Such speeds are typical for loop prominence systems. While a comparison of individual frames does not exclude such a possibility, a movie made from all available frames does not indicate any obvious expanding motion.

4.4. New loop connection on July 4

The growing loops obscured or grew from the eastern inter-connecting loops going from C1f to C3Bf in Figure 3c. The transient bright loop between C1p′ and C4Bp disappeared, whereas the original western loop, connecting C1p′ and C4Ap once again became clearly visible (Figure 3d), and it became multiple (Figure 3e). At midday of July 4 (Figure 3e) one could still see the remnants of the new extensive loops obscuring any connections below them, but a new loop (cf. arrow) became visible connecting C1f with C4Bf. This loop could not be seen at 21^h on July 3, but it was present at 13^h and again was only barely visible at 22^h on July 4 (Figure 3e). Hence it was a transient phenomenon again. It might have had some relation to an SB subflare which occurred in C4 at 2^h01^m on July 4, associated with a type II radio burst. If so, however, the relation must have been indirect, i.e., due to related changes in the magnetic field; any direct effect (particle injection or heat conduction) could not survive from 2^h to 13^h when we saw the loop brightened (Figure 3e; *cf.* Švestka *et al.*, 1977).

4.5. Birth of region C7 and its reconnection

At midday of July 5 a quiet situation has been restored (Figure 3f), C1f and C4Bf, as well as C1p′ and C4Ap being interconnected with several loops. In the evening hours of July 5, however, a new active region, C7, was born to the east of C1, and *from the first time we saw it* (21^h19^m) *it was interconnected through a clearly visible loop with* C1f (cf. arrow in Figure 3g).

As we mentioned in an earlier paper (cf. Figure 3 in Švestka *et al.*, 1977), this is the most common way that new interconnecting loops seem to be born: a new region emerges close to the roots of existing field lines extending outward from an older active region, and the magnetic connections, invisible before, can be seen suddenly in soft X-rays. More generally, as we saw, e.g., in Section 4.2, *newly emerging flux tends to make existing loop connections visible in X-rays.* In order that this happens, one would expect that the newly emerging magnetic field should at least partly reconnect with the magnetic loop that brightens. In the case of region C7 the X-ray brightening at the site of the newly emerging flux was not visible at 13^h15^m on July 5 (Figure 3f); it was first seen at 21^h19^m on the same day, already interconnected with C1f. At 17^h the Mount Wilson magnetogram showed only the following polarity of the newly emerging field which could not connect with C1f. Thus, if the lines reconnected, the reconnection was accomplished most probably between 17^h and 21^h, i.e., 4 hours or less after the birth of the region.

The quick reconnection, indicated in this case, differs strikingly from that we discussed in our earlier paper (Švestka *et al.*, 1977), where the process leading to the reconnection could have required longer than 33 hours. As a matter of fact, the two cases differ in several aspects: in the earlier case the reconnecting loops first had to be built and their movement was slow; in the present case the reconnecting loops had existed since the onset of emergence, and the field motions were fast, which can speed up significantly the reconnection process.

In Section 6.2 we show an example that the field lines need not necessarily reconnect in order to cause brightness variation in an X-ray loop, and this problem has been discussed in more detail by Nolte *et al.* (1977). Even if we have here a case of real reconnection, a problem arises about *when* the reconnection actually was accomplished:

One possibility, discussed above, is that the field reconnects as soon as we see the loops. However, another alternative is that the loop visibility in this phase is due to indirect effects of the field emergence (cf. Nolte *et al.*), and that the reconnection only occurs when the loop brightens strikingly (Švestka, 1977). Next section discusses the brightening of the present loop, while other examples were shown in Section 4.2 and in another of our papers (Švestka *et al.*, 1977). In that other paper, it was assumed that reconnection occurred prior to the brightening. However, as Nolte *et al.* have pointed out, one would expect that the response of the solar corona to the reconnection process would be more powerful than just making a loop slightly visible in X-rays.

4.6. Brightening of the loop connections

Figure 3g shows the situation at about 00^h on July 6. The next series of X-ray photographs was obtained only at 13^h52^m. By that time the loop between C7p and C1f had brightened strikingly (Figure 3h). There was a subflare exactly at the same time in C7 (onset 13^h50^m, maximum 14^h00^m), but since the loop was quite bright already at 13^h52^m, it is not likely that this subflare, peaking only 8 minutes later, could have produced the brightening. There were several subflares earlier on that morning in C7 (the last one at 12^h14^m), but all of them were very small events without any associated radio bursts. Thus, similar to our conclusion in Section 4.2, *the brightening did not seem to be caused by any particular flare.* It probably reflects a response of the loop to magnetic field variations in the growing active region, of which another consequence was the frequent flaring. As we mentioned in the preceding section, the brightening might be a manifestation of the reconnection of field lines between the old and new magnetic fields, for which the emerging flux (and possibly the flare) could serve as a catalyst.

However, there is one more confusing problem related to this brightening. As one can see from comparison of Figures 3g, 3h, and 3i, the loop interconnecting C7p with C1f was not the only one that brightened. At the same time also the interconnecting loops between C1 and C4, especially those going from C1f to C4Bf, (but also those between C1p′ and C4Ap) became much more distinct than before (Figure 3g) or afterward (3i). This effect can be seen still more pronounced through filter 1, with passband 2–17 Å, which indicates an increase in temperature rather than in density. One could think of three alternative explanations for this:

(a) There was a field variation and/or a flare in C1 which influenced both the loop systems going from C1f to C7p and C4Bf. But there was no flaring in region

C1 for 19 hours preceding Figure 3h. On the other hand, there was a striking field increase and intense flaring in region C7 so that it is much more probable that the source of the brightening of the C7–C1 loop is to be found in C7.

(b) The brightening of the connections between C1 and C4 might be independent of the effect seen in the loop C7–C1, being related to field variations and flaring in region C4. There was an interesting subflare in C4 six hours prior to Figure 3h (at 7^h25^m) which covered a sunspot umbra (NOAA, 1973). Thus, region C4 showed significant activity and this explanation cannot be excluded.

(c) However, there is still an alternative explanation. In a recent paper Fritzová *et al.* (1976) showed that there may exist 'sympathetic' active regions which have a common source of activity in subphotospheric layers. Because of this common source, there are periods when the activity in such active regions is synchronized. Regions of this kind must be close together and have a common origin, i.e., one should find them in complexes of activity. Therefore, one cannot exclude the possibility that the apparently simultaneous brightening of many loops in the activity complex, shown in Figure 3h, is due to an enhancement of a subphotospheric agent common to all the components of the complex of activity. Sudden enhancement of Alfvén wave production in the convective zone, e.g., might be an explanation for it (cf. Švestka *et al.*, 1977 and references therein).

4.7. The magnetic connections

Figure 3m shows the loop structure at 14^h on July 6 (Figure 3h) in relation to the underlying photospheric magnetic field seen 10 hours later. At that time region C1 had a well-developed system of internal loops connecting C1p and C1f both on the northern and southern side. C1f was interconnected with C4Bf across the equator and with C7 and C5 on the northern hemisphere. (C5 was the remnant of an old region which expanded westward and became interconnected with C1f, but it actually did not belong to the activity complex.) C1p itself was not interconnected, but its detached part, C1p′ interconnected both with C4Ap and C4Bp. In addition, C4Bp was also interconnected with the ephemeral region C6.

When one compares this situation with the development demonstrated in Figure 3, one finds that *the basic connections between the different polarity islands stayed well preserved during the whole transit across the disk,* in spite of the fact that the shapes and positions of individual *visible* loops greatly varied from one picture to another. An example of how such variations happen can be seen in Figures 3i, j, k. These pictures demonstrate the striking changes that occurred in the loops interconnecting C1 and C7 on July 7 and 8. One can find two reasons for them: a slight clockwise rotation of region C7, which was probably responsible for the twist of the loops in Figure 3j, and a growth of the preceding polarity in C7 which led to the spreading out of the loops in Figure 3k. Regions C1 and C4 showed similar perturbations: C1 rotated counterclockwise and C4 shifted to the east. These changes produced variations in the shape and visibility of individual loop-connections, but the basic magnetic interconnections obviously survived all these motions well.

Changes of much deeper significance, however, began to occur on July 7, when the polarity C4Af began to shrink, and consequently C4Bp started to merge. This process of merging was fully accomplished during 8 July, when C4Af completely disappeared. As one can see in Figure 3l, this also led to a disappearance of the western loops interconnecting C1p′ with C4p. Thus, when the activity complex arrived at the western solar limb, only the connection between the following polarities in C1 and C4 remained visible in X-rays. Still, the magnetic connection C1p′–C4p did not disappear, because we willl see it once again in the next rotation.

4.8. Flare activity

Region C1 produced several important subflares and class 1 flares when it emerged from behind the east limb on 28 June. Five of the flares on June 29 to July 1 had distinct impulsive phases with simultaneous type III and microwave radio bursts which indicates that the region was a significant accelerator of electrons during those days. This activity ended with the subflare at 8^h on July 1 that might have produced the growing loops shown in Figure 3d. After that the flare activity decayed until a new series of flaring started in the late afternoon of July 3. This period was characterized by frequent production of type III bursts (associated with 17 flares) while microwave bursts were usually missing. This period of pronounced type III activity ended shortly after midnight of July 7/8. After that, through July 10, the region began to produce two-ribbon subflares with distinct microwave bursts, but no type III's could be seen any more. This activity may have been the result of the growth during this interval of a positive (preceding) polarity feature in C1f, which gave rise to a new hot core in the active region, very bright in the hard filter 1 (3 to 17 Å) pictures. No loops could be identified with this feature, which appeared first on July 6 and was imbedded in the midst of rather strong negative fields, giving the region a complex figuration.

Region C4, too, was an intense producer of type III bursts, and was associated with at least 16 flares from June 29 to July 4. Several flares also showed distinct impulsive microwave bursts and four of them, two on June 29, and one each on July 7 and 8, produced type II bursts in the metric range (NOAA, 1973). Since type II bursts represent shock waves closely related to the second stage acceleration in flares (Švestka and Fritzová-Švestková, 1974) one would expect that the acceleration of protons to MeV energies and of electrons to relativistic energies was occasionally accomplished in C4. This cannot be checked on June 29 when the activity complex was on the east limb because the energetic particles could not easily propagate to the Earth. However, even after the type II bursts on July 7 and 8, there was no apparent enhancement in the particle flux (Krimigis, 1976; Wenzel, 1977) contrary to our expectations.

The only other region that flared was C7 in which subflares began to appear on July 6. Three of them produced type III bursts, but generally the subflares were not important and not of the impulsive type. (In contrast to C1, which was intermittently complex, and C4, which had a complex structure, C7 was a purely bipolar region.)

4.9. Connections to surrounding fields

As one can see in Figure 3, region C1 was also interconnected through faint but clearly visible X-ray loops with some scattered fields in the surroundings. The loops going to the NW, best visible on Figures 2 and 3b, c, d, connected C1p with remnants of old positive fields – the unipolar area mentioned above in Section 3; the long loop going to the SE on Figure 3d connected C1f with a small island of negative field far to the east of C4; and we mentioned earlier the connection of C1f with C5 (cf., Figure 3m), which was a travelling remnant of an old region alien to the activity complex (McMath 12377 in rotation 1602 and 12358 in rotation 1601).

All these old fields existed in that part of the solar surface prior to emergence of C1. Therefore, the visibility of these loops in soft X-rays is another suggestive indication that *the emerging new fields reconnected, sooner or later, with some of the old weak fields which existed there before.* In contrast to the loops that interconnect active regions, *these loops, stretching out to old field remnants, have a strikingly stationary nature,* often surviving in the same shape and brightness for many days.

4.10. The sharp boundary of C1

The northwest boundary of C1, seen in Figure 3, is a remarkably long straight line. This boundary may also be seen as a straight line in the northeast boundary of the magnetic fields in the early portion of the disk passage (July 2–5). Several faint loops stretch from this boundary to the weak unipolar area, which is oriented rather parallel to the magnetic boundary in C1. No large filament was associated with this magnetic polarity boundary, nor with the other boundaries in this set of unipolar areas in the north. This characteristic sharp boundary will be discussed in more detail in the analysis of the next rotation.

5. Rotation 1604

In its third rotation, region C1 appeared from behind the east limb as an old, extensive but spotless, active region. Still it produced a powerful two-ribbon 'spotless' flare on July 29, the most outstanding flare event observed during the whole period of the Skylab mission.

Region C4 still contained minor magnetic complexities, but its basic complex structure, i.e., the separation into two bipolar configurations, C4A and C4B, did not exist any more. We saw that this simplification actually happened shortly before the region reached the west limb in the previous rotation.

The most striking change in the structure of the activity complex was a relative shift in the location of the polarities. Because of a continuing clockwise rotation of region C1, westward expansion of C1p, and westward shift of region C4, the portions C1p and C4f, which are the same polarity, occupy now the same longitudes (cf. Figure 2). Since loops do not care to connect these two areas, there appears to be a dark region separating them whereas the loops can connect only across the end of this void (Figures 2 and 4). Nevertheless, *the general pattern of the loop structure is still similar to that seen one rotation before.*

5.1. Situation prior to the flare of July 29

On the east limb, on 26 July, the internal X-ray loops in region C1 extend (in projection) to an altitude of 260 000 km above the solar limb. On the disk (Figure 4a) one can see, in a somewhat altered shape, the old connections C1f-C4p, the latter one obviously having been restored after its disappearance when C4Af dissolved. However, a black corridor divides these two interconnections, because of the absence of any field lines connecting the extensive and co-longitudinal fields C1p and C4f. Also the interconnection C1f-C7p still exists.

There was a subflare with a type II radio burst at 00^h00^m on July 26 in C1. However, the high loops seen above the limb could not be directly associated with this subflare, because one can see them already on July 25 and 24, still behind the limb. Moreover, their altitude would correspond to a speed of growth in excess of $36 \mathrm{~km~s^{-1}}$ if they were produced in the subflare, and this is an unusually high speed for a growing loop-prominence system. Thus these high loops obviously represent the general shape of the active region as seen at the limb at this phase of its evolution.

5.2. The flare of July 29

The major flare of July 29 started at 13^h10^m and its development in the chromosphere has been described in detail by Michalitsanos and Kupferman (1974). It started with a filament disappearance and had the typical regular two-ribbon shape, characteristic of spotless flares (Dodson and Hedeman, 1970). In soft X-rays, unfortunately, the first picture was obtained only at 16^h43^m. At that time the X-ray flare (Figure 4b) exhibited a system of bright loops reaching (in projection) an altitude of $\geqslant 110\,000$ km. The sharp edge in Figure 4b is the western flare ribbon in which the loops are rooted. The bright eastern edge consists of brightenings caused by an increased path length along the line of sight at or near the tops of the loops. After this first X-ray picture the loops still continued to grow with an average speed of $\sim 0.65 \mathrm{~km~s^{-1}}$ from 17^h to 24^h on July 29 and $\sim 0.2 \mathrm{~km~s^{-1}}$ on July 30.

A comparison with the Hα photographs (cf. Figure 20b in Švestka, 1976) shows that the X-ray loops were approximately cospatial with (or only slightly higher than) faint dark Hα loops recorded by Michalitsanos and Kupferman. Thus there is little doubt that we observed a growing loop prominence system in X-rays. A more detailed discussion of the X-ray observations of this flare is planned as a part of the second ATM Workshop (on solar flares).

It has been suggested by Schröter (cf. Švestka, 1976, pp. 33 and 34) that major flares of this type, originating in relatively weak magnetic fields, should be used for checking whether some recognizable fraction of the magnetic energy in the active region was used for the flare production. The relative change of the

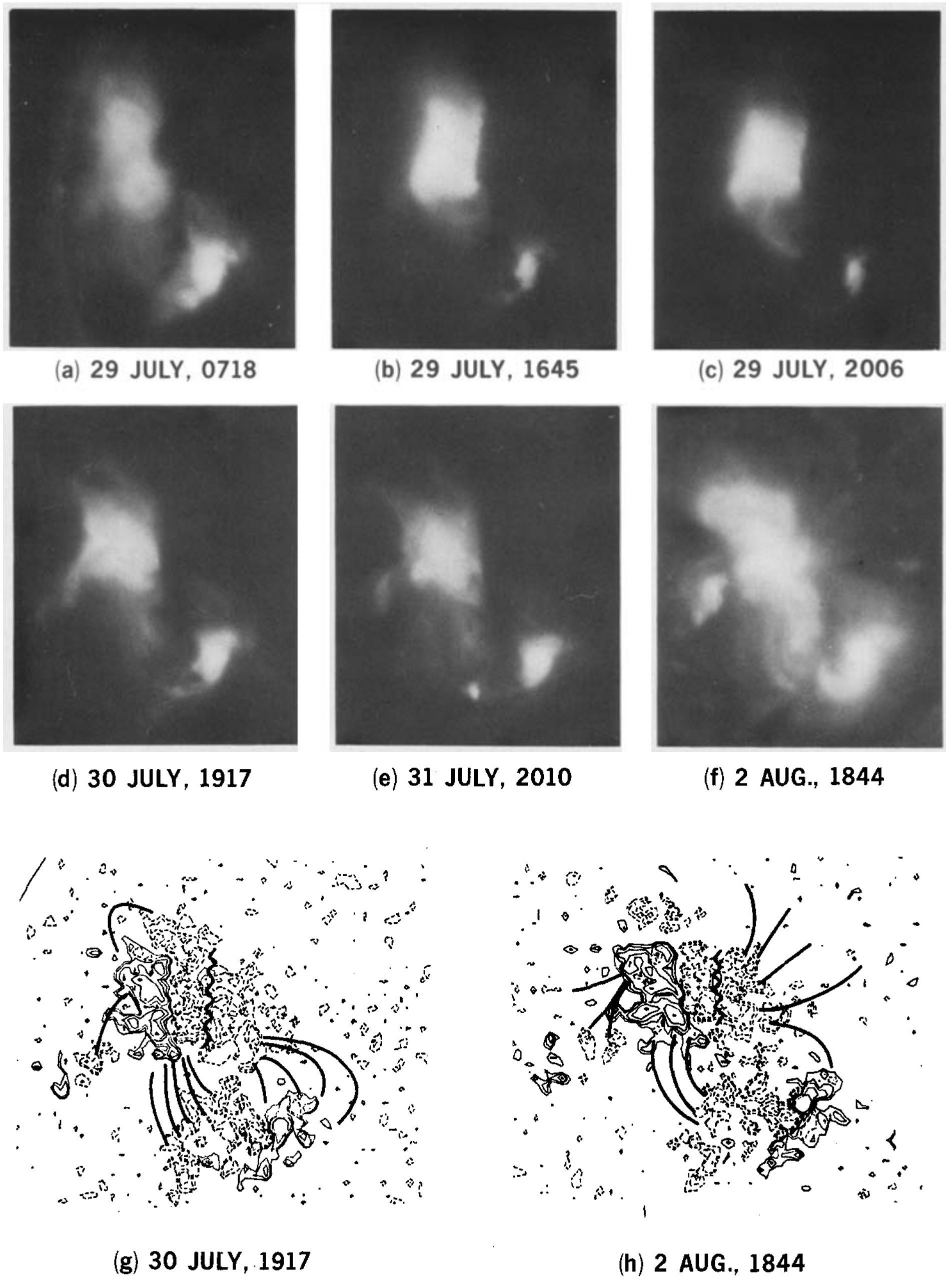


Fig. 4. The development of the complex of activity in rotation No. 1604, from July 29 to August 2. It shows the 3B-importance flare loops in (b), the preflare situation in (a) and the post-flare configuration in (c) to (f). Pictures (a), (b), (d), and (e) were taken through filter 3 with a 16 s exposure in (a), (d), (e), and a 1 s exposure in (b). Picture (e) was taken with a 64 s exposure through harder filter 1 (2–17 Å). Picture (g) shows the rich system of loops on July 30, in projection on the Mt. Wilson magnetic field map. The wavy line marks the position of the western foot-line of the X-ray loops. This was first the western bright flare ribbon in (b) and (c), and later on, in (e), it became the western boundary of the X-ray emission in the active region C1, still strikingly sharp even in Figure 5. Picture (h) shows renewed loop connections from C1p to the old UMR to the west. Note that these loops as well as any recognizable scattered positive field were absent in picture (g).

photospheric field should be much more pronounced in this case than in fully developed sunspot groups. Michalitsanos and Kupferman (1974) could not discover any obvious changes in the morphology of the magnetic field after the flare, but they could not determine the field strengths. We could at least estimate them, but still *we also were unable to find any obvious change associated with this 3B-importance flare.*

5.3. Brightening of the transequatorial loop

The interconnecting transequatorial loop C1f–C4f brightened between 16^h43^m and 18^h21^m (Figure 4c) and returned to its previous brightness again between 21^h40^m and 24^h40^m on July 29. The duration of this brightening (3.5 to 8 hours) is similar to that in another transequatorial loop we discussed elsewhere (Švestka *et al.*, 1976). As we showed there, the duration of the brightening can be interpreted well as radiative cooling with $n_e \approx 10^9$ cm^{-3}. The origin of the brightening, however, is not clear at all. It occurred more than 3 hours after the major flare and there was no other flaring in that region. The brightened loop was rooted inside the 'tunnel' of loops remaining after the flare, in a peninsula of C1f polarity. The next day there was an additional magnetic peak in this peninsula so that the loop might have brightened when the second peak was born. In any case, as for most of the other brightenings, *the enhancement was not directly associated with the flare*, but rather with some magnetic field change in the flaring active region.

5.4. Post flare situation

Figure 4d shows the late post-flare situation in the evening hours of July 30. We see a very rich system of transequatorial loops interconnecting C1p′ with C4p, and C1f with C4f (cf. Figures 2 and 4g). The dark gap between these two sets of loops is due as stated above to the absence of any magnetic connections between C1p and C4f and, in particular, to the fact that *there is no visible X-ray emission over the C4f polarity.* Also the X-ray emission over the western part of the C1p polarity is cut off where the post-flare loops end. Still, however, in spite of the misleading shape of the X-ray emission, we encounter the same system of loops we saw on Figure 3m one rotation before.

As we pointed out in Section 4.2, *none of the loops we see connect to sunspots.* Since we have seen the same situation before (Švestka *et al.*, 1977), this appears to be a general rule for all the interconnecting loops we see in soft X-rays (Švestka, 1977).

The wavy line in Figure 4g marks the position of the 'sharp edge' of the X-ray flare which coincided with the eastern flare bright ribbon. It obviously represents the western boundary of the closed field in region C1, which we see emitting in X-rays. To the west of the wavy line, where no X-ray emission can be seen, the field is most probably open to more distant areas of the Sun because the sharp boundary suggests a demarkation between open and closed field lines. Indeed we can see in Figures 4f and h that the field from this portion of C1 was rooted to the west. This is an illustrative example of how biased may be the sample of magnetic connections we see on the X-ray images.

The connection C1f–C7p still exists, even when it is partially covered by remnants of the flare loops in Figure 4d. Figure 4e shows this connection more clearly.

There is a difference of 24 hours between pictures 4d and 4e, and it is of interest to see the daily variation in the loop system C1f–C4f. Almost every loop now is different. This demonstrates what we said before: *while the system of magnetic connections does exist all the time, the individual loops in it which are visible in X-rays, vary within a <1 day scale.*

Shortly before midnight on July 31, a new system of growing bright loops became visible in region C1 (Figures 5a–c). From 23^h23^m on July 31 to 11^h30^m on August 1 this system grew with a constant (projected) speed of 1.1 km s^{-1}. However, one cannot find any flare that might have initiated these loops, since after the major flare event on July 29 *there were no flares or subflares in region C1 until August* 4. According to Webb (1976) one can see a subtle filament activation around midnight on July 31/August 1. Evidently, growing loop events of this kind need not necessarily be initiated by a flare. There was a change that occurred in the magnetic configuration of the northern part of C1 starting after 18^h on July 31 and extending into August 2. The northern part of C1 stretched eastward in this interval as if a sudden shear developed at roughly 25° N. latitude. It is possible that the loop system seen in Figures 5a–c and the filament activation resulted from this shifting of the magnetic foot points.

On 2 August, a system of internal loops in C4 brightened (Figure 5d), this time apparently following an Sn subflare at 04^h00^m, associated with long-lived X-rays and microwaves and with several groups of type III+V radio bursts. One cannot estimate the expansion of this system since the loops were very diffuse on all pictures except the one shown in Figure 5d.

5.6. Sharp western edge

The sharp western edge of the flare seen in Figure 4b–e is a very spectacular phenomenon. On the magnetic maps (Figure 4g, h) we have marked its position with a wavy line. Obviously, it lay inside the C1p polarity parallel to the neutral line. Apart from the displaced neutral line, however, *the magnetic features themselves did not show such a linear character.* In the previous rotation a similar sharp boundary was noted in the X-ray region and in the magnetic fields. In the interval since the first disk passage, the plage and the magnetic fields have expanded as a part of the well-known aging process of active regions, but in X-rays the boundary seems not to have moved. It is as if the magnetic-field lines responsible for the high coronal loops represent a relatively immovable structure which, however, cannot be distinguished from other surface fields on the magnetograms. To the west of the boundary the field lines probably extend outside the

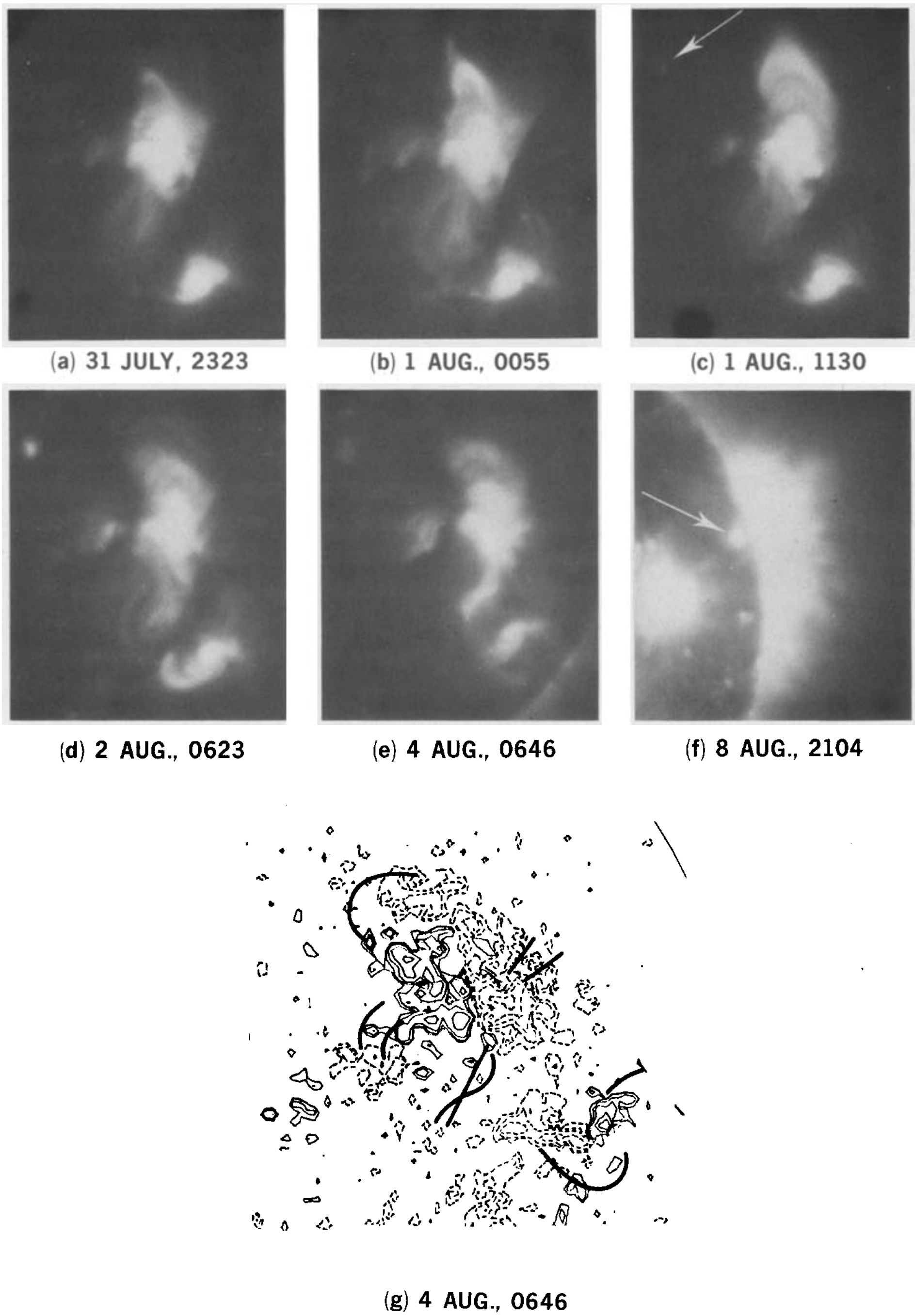


Fig. 5. Further development of the complex of activity in rotation No. 1604, from July 31 to August 8. Pictures (a) and (c) were taken through filter 1 with an exposure time of 256 s. Pictures (b), (d), and (e) were taken through filter 3 with a 16 s exposure. Picture (f) is a 64 s exposure through filter 3. Picture (g) shows the loop structure in projection on the Mt. Wilson magnetic map of August 3.

active region. Such an opening of the field lines deep inside the active region does not seem to be a common phenomenon, and in the case of C1 may be related to the size, or longevity of the region, or it may have to do with the status of C1 as the progenitor of the complex of activity.

5.7. Reappearance of scattered fields

The positive polarity unipolar area immediately to the west of C1 greatly weakened during the passage behind the visible disk, and along with it the loops connecting this area with C1p (Figure 4g). Later in the rotation the sharp boundary became less well defined because loops appeared that again stretched west from C1p (Figure 4f). This coincided with the reappearance of scattered weak positive fields west of C1, starting about August 2 (Figure 4h). Such a sudden large-scale appearance (or reappearance) of scattered magnetic fields can be observed from time to time on the magnetic synoptic charts, but in view of the weakness of the fields involved, one is generally tempted to dismiss such phenomena as likely being of instrumental origin, or due, perhaps, to some large-scale sharp inclination of field lines which renders the features most easily visible only at extreme CM distances. However, here we have a case when the appearance of 'new' weak scattered fields is accompanied by the simultaneous appearance of loops linking these features to existing fields.

It is likely that new magnetic flux does not actually appear suddenly scattered over a large area with long loops of field lines connecting to old fields, but rather the flux was present all the time and suddenly, and on a large scale, by a change in element size (and/or field strength), became visible on the magnetograms. At the same time the pre-existing loops brightened. This hypothesis requires that *scattered magnetic elements over a large area of the Sun behave in unison.*

5.8. Birth of region C9

Figure 5c (cf. arrow) shows the first appearance of X-ray emission associated with the birth of region C9, to the east of C1. This region became the basic northern region of the activity complex for the following four rotations. However, in the first week of its existence the region was quite insignificant; it reached distinct bipolar structure with bright X-ray emission on August 2 and 3 (Figure 5d), but after that it began to decay (Figure 5e) and almost died on August 6/7. A revival came on August 8 and after that time it began to grow fast (Figure 5f, cf. arrow). As we shall see in Section 6, it recurred as a fully developed region next rotation on the east limb. The region did not show any visible interconnection with region C1 prior to August 8, and its proximity to the limb made it impossible to decide whether it was, or wasn't, interconnected after that.

5.9. The complex near the west limb

A brightening (and twisting) of the interconnection C1f–C4f occurred again on August 4 (Figures 5e and g), at about the same time that region C1 revived its flare activity, after almost a one-week pause. A subflare started at 6^h10^m while the X-ray loops brightened between 5^h23^m and 6^h46^m. Again: either the flare itself, or more likely the associated magnetic field variation was responsible for the loop brightening.

On the limb (Figure 5f) the X-ray pictures reveal the very rich structure of loops in the activity complex extending to 180 000 km above the photosphere. It is difficult to identify the loops, but the high ones certainly are internal loops and not those which interconnect the regions.

5.10. Flare activity

Apart from having produced the major flare of July 29 (Section 5.2), the flare activity of the complex was smaller (63 flares and subflares) than in the previous rotation (158 flare events). Most flares were in region C4; seven of them, on July 29 to August 2, produced impulsive bursts, but mostly they were of the quasi-thermal character. Region C9 began to produce subflares only on August 8 and these, too, were without impulsive bursts. However, the activity in C1 is worth mentioning.

There was a flare associated with a type II burst on July 26, when C1 was on the east limb. Several subflares occurred on July 26 and 27, the last one at 13^h40^m on July 27. After that time, for two full days, the region was completely inactive until it gave rise to the 3B flare at 13^h13^m on July 29. But after that, again the region was without a single subflare, for more than five days, until 6^h10^m on August 4. A look at Figure 4a confirms that the region was very quiet even in the corona before the major flare onset. But this was not true during the second, 5-day, quiet period. As Figure 5a–e clearly shows, the coronal loops in the region underwent several striking brightenings and expansions, of which only the last one (Figure 5e) might have been associated with a reported flare. Thus, *the absence of any flaring in the chromosphere does not necessarily mean that the overlying coronal active region is quiet and inactive.*

5.11. Particle emission

Whereas the complex of activity was no abundant source of energetic particles in the preceding rotation, this time it emerged from behind the east limb as a powerful source of a 'permanent' stream of low-energy nuclei: a flux increase was first recorded on July 25 (for > 0.4 MeV protons), steepening around midday of July 26, probably in association with the type II-related flare at 00^h in region C1. This early onset of the 'permanent' particle flux indicates that some particle-producing flares occurred in the complex of activity when it was on the invisible hemisphere; we have seen in Section 4.8 that subflares suspected of accelerating particles to higher energies already were observed late in rotation 1603.

Another rise in flux came shortly after the flare of July 29; this time there were recorded also > 3.5 MeV α-particles and relativistic electrons (Krimigis, 1976). The flux remained greatly enhanced until August 4. This strong particle emission puts the 29 July flare into the rare category of those spotless flares (such as 1967, January 11 and February 13) which accelerate nuclei and relativistic electrons (cf. Dodson and Hedeman, 1970). The absence of large spots suggests that *the magnetic configuration is more important for the acceleration process than the magnetic field strength.*

6. Rotation 1605

In this rotation the old regions C1 and C4 were dissolved further, region C9 grew, and new long-lived regions C12, C13, and C15 appeared in the eastern part of the activity complex. With the exception of the decaying C4 and the new region C15, which was born on August 29, all the activity in this rotation was confined to the northern hemisphere. Therefore, while there were only a few transequatorial interconnecting loops, a very rich system of interconnecting loops developed in the northern hemisphere.

This changed completely the character of the activity complex in soft X-rays (Figure 2 and 6). We no longer see the long diffused loops from the previous rotations, but instead there is a scattered system of bright loops broken into short interconnections. In a way it reminds one of the pictures of Salvador Dali. However, a comparison with the magnetic field maps shows that this seemingly chaotic 'Dali' structure is very well organized, connecting the opposite polarities inside the individual active regions and alternately between adjacent regions, the main chain of loops being C1p-C1f-C11f-C9p-C9f-C13p-C13f (Figures 2 and 6).

6.1. Altitude of the loops

When emerging from behind the east limb, visible X-ray loops were highest (~180 000 km) on August 22/23; on the west limb the highest loops (~190 000 km) were seen on September 5. This indicates that during this rotation C9 was the region with the best developed internal loop system. The loops were inclined northwards so that the distance along the loop-plane between the top of the loops and the solar surface was in excess of 200 000 km.

On August 23, one could see above the limb also the loop interconnecting C1f with C9p (Figure 6a, cf. arrow). This loop was quite high, too, extending to an altitude of at least 110 000 km.

6.2. The old interconnections and the birth of C12

Figure 6a shows also the interconnecting transequatorial loop C1p′–C4p, well known from the previous rotation. This loop became quite distinct once again around 0^h on August 26 (Figure 6b, cf. arrow); it still could be seen as a diffuse feature until August 29, but after that its visibility became doubtful. It was obviously decaying jointly with the decay of the scattered fields C1p and C4p. No flare could be associated with the distinctiveness of the loop on August 26, either in C4 or in C1.

The other connection which existed one rotation before, between C1f and C4f, could not be seen, because a new region C12 was born close to its northern roots before the old connection might have become clearly visible. This new region, born on August 5 close to the equator (3° N), very quickly showed visible connections with scattered fields to the south of the equator which were remnants of the disintegrating C4f. One can see the first visible loops in Figure 6b, and the fully developed system of the resulting 'loop spider' on Figure 6c. Map 6d, corresponding in time to Figure 6b, with a magnetogram from 18^h on August 25, shows the new emerging positive flux (which later became C12f) interconnected with the remnants of C4f.

This event again might be considered to be a case of line reconnection. The 'spider loops' one sees in Figure 6c existed before, connecting C1f with C4f (cf. previous rotation, best seen on Figure 4d). They were not visible in X-rays for most of the time, until new flux emerged near their northern root-points on August 26. Within 24 hours (cf. 6b and c) the loops became outstanding in X-rays. Thus either the loops reconnected from C4f to C12f, or the northern root-points were moved by the emerging flux thus deforming the loops and making them visible through motion-induced emission.

In this case, however, in contrast to those we discussed earlier, the data tend to indicate that the field lines did not reconnect. One can see in Figure 6c that the loops, indeed, seem to be deformed by the emerged magnetic field. But what is more decisive, is the magnetic situation sketched on map 6e: the loops, which according to our expectations are rooted in scattered remnants of the field C4f, aim in the north at C12p, i.e., a region of identical polarity!

This observation does not exclude reconnection as one of the processes which makes loops visible in X-rays, since the absence of reconnection here can simply be due to the fact that the new flux emerged at the 'wrong' place. But it gives evidence that *loops can also be excited to emit in X-rays without the reconnection process*, in the manner suggested by Nolte *et al.* (1976).

It is of interest to see that we meet here again with a dark 'corridor' similar to that seen between C1 and C4 in the previous rotation, and even with the western 'sharp edge' in C1 which was so striking after the major flare of 29 July. As in the previous rotation, we see the corridor because of lack of X-ray emission above C4f and over the western part of C1p. In C1 the western foot points of the active region loops are still aligned parallel to the straight shape of the zero line between C1p and C1f. This shows how slow the changes of large active regions can be in the late phase of their developments. As we mentioned earlier in this Section, note (in Figures 6d and 6e) that even the tiny polarity island C1p' (cf. Figure 3m) is still present after two rotations and still interconnects with C4p.

6.3. Loop brightening and filament disappearance

Some transient loop brightenings occurred in C1 and C11 on August 27 and 28, without any obvious flare associations. We skip these and pay attention only to an August 29 event, in which an interconnecting loop between C1 and C12 brightened in a conspicuous way.

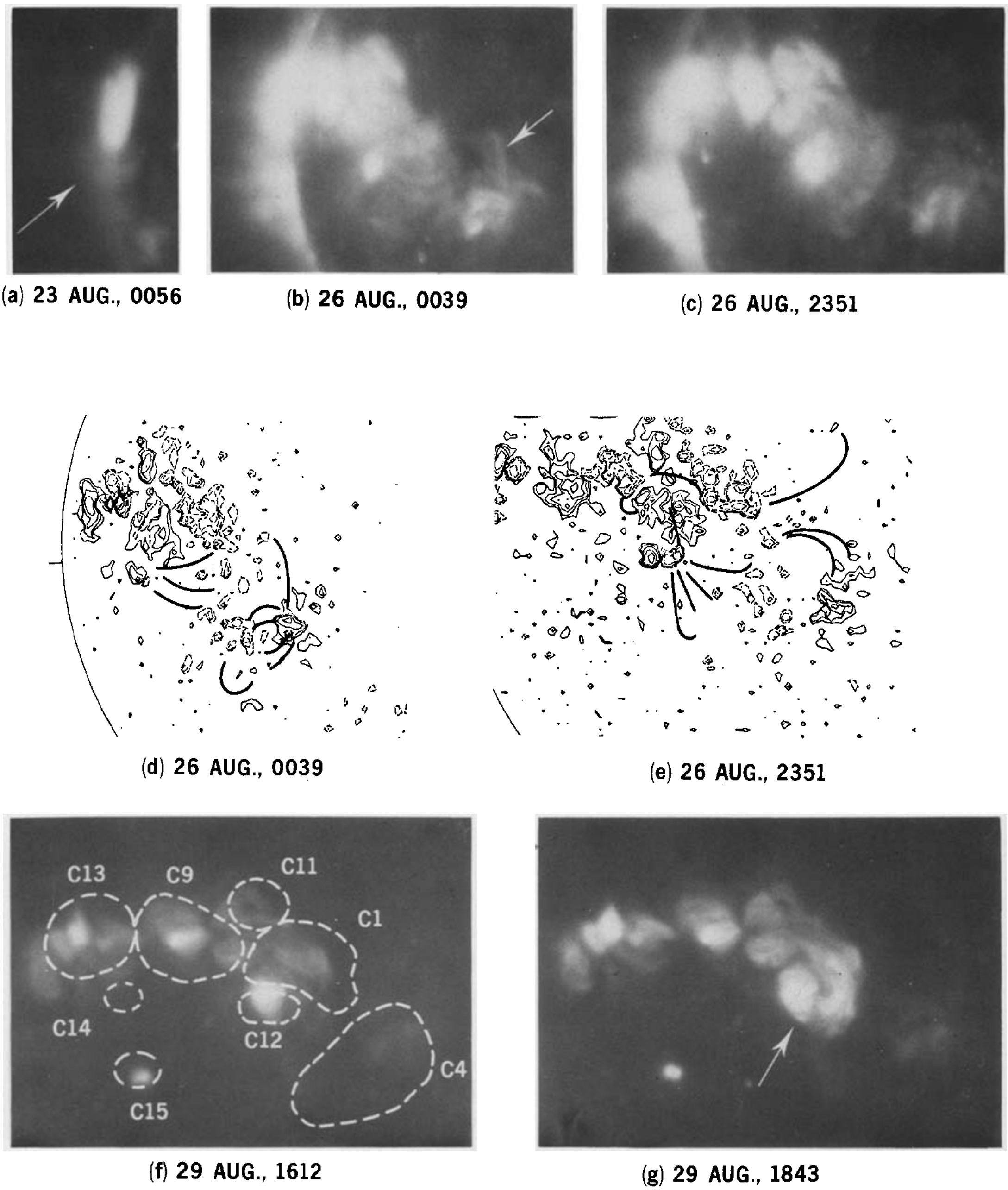
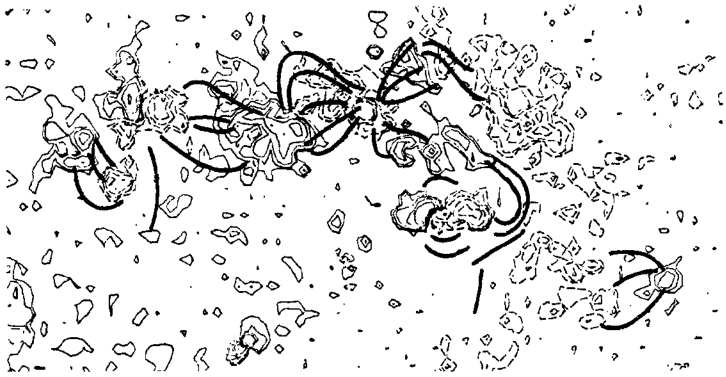
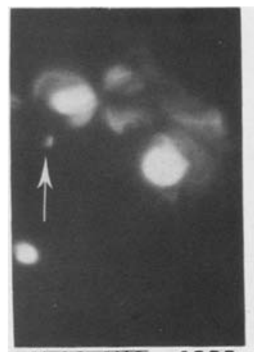


Fig. 6. The development of the complex of activity during rotation No. 1605. The pictures (a), (f), (g), (l), and (m) were taken through filter 3 with a 16 s exposure. Pictures (b) and (c) were taken through filter 3 with a 64 s exposure. Pictures (i), (j), and (k) were taken with a 256 s exposure through filter 1. Pictures (d), (e), (h), and the right-hand part of (i) show the loops visible in X-rays in projection on Mt. Wilson magnetic maps.

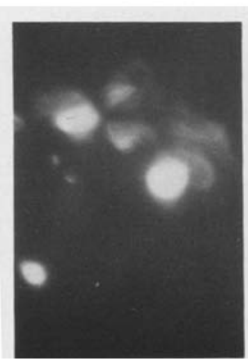


(h) 29 AUG., 1843

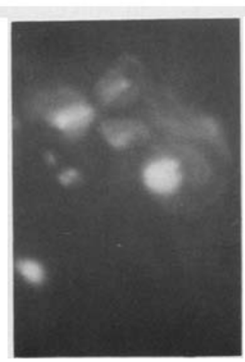
(i) 30 AUG., 0244



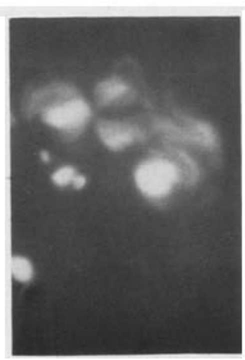
(j) 30 AUG., 1338



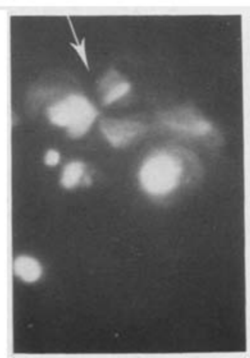
(k) 30 AUG., 1936



(l) 30 AUG., 2106



(m) 31 AUG., 0011



(n) 31 AUG., 0657

Figure 6f shows the situation in the activity complex prior to the brightening, at 16^h12^m. It also demonstrates the general appearance of the activity complex in this rotation, and we have marked on it the extent of the individual active regions. In this figure, one cannot detect any connection between regions C12 and C1. Two hours later, however, between 18^h10^m and 18^h38^m, a bright system of loops interconnecting C1p and C12p appeared in the western part of the complex (Figure 6g). Figure 6h shows the distribution of all the visible loops at that time as projected on a magnetic map. There was no flaring at all in the activity complex on August 29 prior to this event, and the brightening was clearly connected with a filament disappearance (for details see Rust and Webb, 1977). A similar brightening in almost the same position also occurred at 06^h on September 1.

Another big filament disappearance event was observed in the northwest part of the activity complex at about 20^h on September 1, and this has been described by Rust (1976). It is of interest that *all these disappearing filaments, while still greatly enhancing the adjacent corona, did not produce any flare brightenings in the chromosphere.* This is a difference compared with the preceding rotation where the same filament channel after its disruption produced the major flare of July 29. Obviously, *region C1 is now too old to produce flares, while it is still capable of activating filaments almost every day.*

6.4. A CORONAL STREAMER?

For the whole day of 29 August region C12 showed a southward directed small bright internal loop (cf. Figures 6f, g, cf. arrow, h) which slowly expanded and reached a maximum projected altitude of $\sim 100\,000$ km at about 6^h on August 30. After that the projected altitude began to decrease again (so that the loop was either shrinking, or assuming a more radial direction, or simply higher loops were losing their brightness).

Since the first time the loop was seen, at 6^h35^m on August 29, it was associated with a peculiar straight spike which appeared to begin at its top and extend southward. There are no magnetic features in this direction which might explain it as a long straight loop, and there is no known flare in C12 which might have produced an ejection.

One can see the feature in Figure 6f, but its best visibility was at about 2^h on August 30 (Figure 6i, cf. arrow), and it decayed during the evening hours of August 30. There is a possibility that we have seen here a rare case of a transient coronal streamer visible in soft X-rays in projection on the disk. Unfortunately, it was rooted close to the center of the disk and directed from the northern hemisphere toward the south so that the white-light coronagraph on Skylab was unable to confirm its existence over the limb (MacQueen, 1976).

Some authors associate coronal streamers with type III radio bursts. It may be therefore of interest to note that a long and intense series of type III bursts started on August 29 at 13^h10^m, produced several outstanding groups of bursts near 16^h30^m, 17^h00^m, and 18^h40^m, and decayed after 7^h on August 30. There is, of course, no evidence that that this activity was related to C12, and it might equally well have stemmed from McM 12507 near the east limb.

6.5. Newly born regions and the 'Dali' structure

An ephemeral region C14 was born on August 28 in the position marked on Figure 6f, but it had no visible connections with the other regions and died within one day. More to the south, region C15 was born on August 29 (Figures 6f–n). This new southern region survived three subsequent rotations, but it showed no distinct interconnecting loops going to the northern part of the complex during this rotation. This may be an indication that this region was not a part of the complex. Finally, on August 30, region C16 was born inside the northern complex, and this development is worth a short discussion.

In X-rays, a brightening was first seen at 5^h51^m on August 30. A short point-like loop brightened during the morning (compare Figures 6i and 6j, cf. arrow) which connected the newly emerging flux (still invisible in X-rays) with small polarity islands near the edge of C9f. A western loop was added to it in the afternoon (Figure 6k). This western part began to develop very fast (Figures 6l, m), and it finally developed an interconnecting loop with C12 (Figure 6n). This interconnecting loop could scarcely have existed before, because C16 developed in an old portion of positive field, and the interconnection is to a positive field as well (C12f). Thus this loop seems to have been newly born, within some 12 hours.

Region C16 demonstrates in a very illustrative way the nature of the 'Dali' structure of the system of loops in the activity complex. Loops are visible wherever they cross the zero line dividing the magnetic polarities, but not above the polarity islands themselves. Thus we see (Figure 6k) one loop going from C16f to a feature of opposite polarity outside the region, and another one connecting C16f and C16p. This latter one, which is 'the active region proper' develops in a system of loops in Figure 6l. Later on (Figure 6m) we also see loops connecting C16p with outside features to the west. In a similar way we may get the other loop systems in Figure 6, for example those resembling parted hair, in the fountain shown on all the Figures 6f–n (cf. arrow in Figure 6n): the eastern loop system is the internal system in C9 (cf. Figure 6f); the northwest system of loops interconnects C9p with C11f; and the southwest system interconnects C9p with C1f. The dark 'apex' is the central part of C9p. In this manner one can easily understand the whole peculiar X-ray structure of the activity complex in this rotation: dark where the longitudinal magnetic fields are strongest and brightest where the transverse field reaches its maximum.

There are two main reasons why the X-ray pictures of the activity complex in this rotation have this strange character – different from essentially all other situations we have seen during the Skylab flight:

(1) The active regions, being older, do not have compact cores like, e.g., all the regions in Figure 3. Thus we see the structure of the internal loops in all the regions, the only exception being the newly born and developing region C12.

(2) All the regions are very close together so that all are interconnected with visible systems of loops which greatly resemble loop systems in the active regions themselves.

The combination of (1) and (2) leads to the 'Dali' structure we see, because *as time progresses the internal loops become indistinguishable from the external loops.* We would need to see more complexes of activity in the corona to be able to decide whether this is a typical phase of development in an activity complex in which the active regions are so close to one another and probably have a common subphotospheric source of origin.

6.6. Flare activity and particle production

The flare activity of the complex was very low in this rotation: altogether there were 41 flares or subflares, of which 39 occurred in the newly born regions, most of them in C16 (18 events) and C12 (14 events). Only one of them, on September 6 at 9^h12^m, in C16, was a big flare (1B with strong microwave burst). The only and last flare in C1 occurred on August 21 when C1 was on the east limb. Meudon classified it as of 2N importance in Hα, and its X-ray event lasted for more than 3 hours on SOLRAD 9 (NOAA, 1973). It was associated with a strong type IV burst and most probably was the source of particles which arrived at the Earth on 22/23 August. This particle flux then declined for about a week, and no other particles were apparently emitted from the activity complex during this rotation. As we mentioned in Section 6.3, there were still many filament activitations in C1 after the flare of August 21, but not a single one produced any chromospheric brightening which might be classified as a flare or even a subflare event.

7. Rotation 1606

Region C1 came back greatly dissolved in this rotation and the southern region C4 could no longer be identified. Thus it is clear that also the transequatorial interconnections between C1 and C4, still visible in the preceding rotation, no longer existed. The regions more to the east did not show any distinct transequatorial connections either.

On the other hand, most of the rich network of east–west loops, so prominent in the previous rotation, was still well preserved (Figures 2 and 7). Nevertheless, the complex does not have the 'Dali' structure any more, because of great intensification of regions C9 and C16, which have practically merged into one on the magnetograms, a weakening of C1 and C13, and the decay of C11. Regions C9 and C16 become now the most active regions of the complex; C16 grew fast after its birth on August 30, and C9 revived after a rather inactive period in the previous rotation.

Both these regions showed rather high X-ray loops on the solar limb, on September 19 ($\sim$160 000 km) and October 3 ($\sim$190 000 km). These may be both interconnecting and internal loops, but the highest ones on the western limb were clearly internal loops in C9, as in the rotation before (cf. Section 6.1). Also Figure 7a shows that most of the loops, including the highest of them, diverge to all directions from C9. Figures 7b and c show the loop system on the disk.

7.1. Activity in the complex

Region C15, while aging and dissolving, produced a type II burst flare at 17^h48^m on September 23. We do not have any X-ray photograph of this flare, only pictures before (Figure 7b) and after (7c) the phenomenon. A comparison of these pictures shows that loops might have expanded after the flare, similar to the cases for several other events earlier, and a resulting bright cloud can be seen on Figure 7c to the southeast of C15. The interconnection to an 'appendix' C15f′ to the west (cf. arrow in Figure 7b), however, did not change much. It is much brighter in Figure 7c, but its extension far to the southeast is about the same. The reason for the intensification of these loops seems to be field variations in C15p′, not the flare which occurred 7 hours before. No Hα flaring was reported in C15 at that time, but one can see that the foot point of the loops showed a flare-like X-ray brightening.

Figures 7d and 7g show the details of the loop systems in the activity complex and their projection on the magnetic map. Although there may be interconnections across the equator, the situations are local and small-scale. These pictures also show region C17, newly born deep in the south on September 25. This region lived for only 3 days and it was apparently never interconnected with the other regions in the complex of activity.

Starting in the morning hours of September 25, the northern internal loop system in C9 began to exhibit striking brightness variations, lasting for almost two days (example in Figure 7e). No flare can be clearly associated with it; however, the quiescent dark Hα filament lying below this arcade of loops went through significant shape variations during these days. Thus the Hα filament activations and the X-ray loop brightenings were apparently related phenomena.

Generally, the flare activity in the complex revived during this rotation, particulary in C9, where 41 flares and subflares were recorded. On September 24 the flares in C9 were associated with type III bursts, but starting with September 25, when the filament activations and loop brightenings began to occur, all the flare events were rather insignificant and apparently did not accelerate particles. Other flare-productive regions were C12 and C16. Activity in C15 practically died with the type II-burst flare on September 23, mentioned earlier in this section.

The particle flux increased on September 23. It might have been associated with the type II-burst flare in C16, but the exact onset time of the particle enhancement is not known (Krimigis, 1976). Another flux increase was recorded in the morning hours of September 27, but we were unable to discover any source for it on the solar disk.

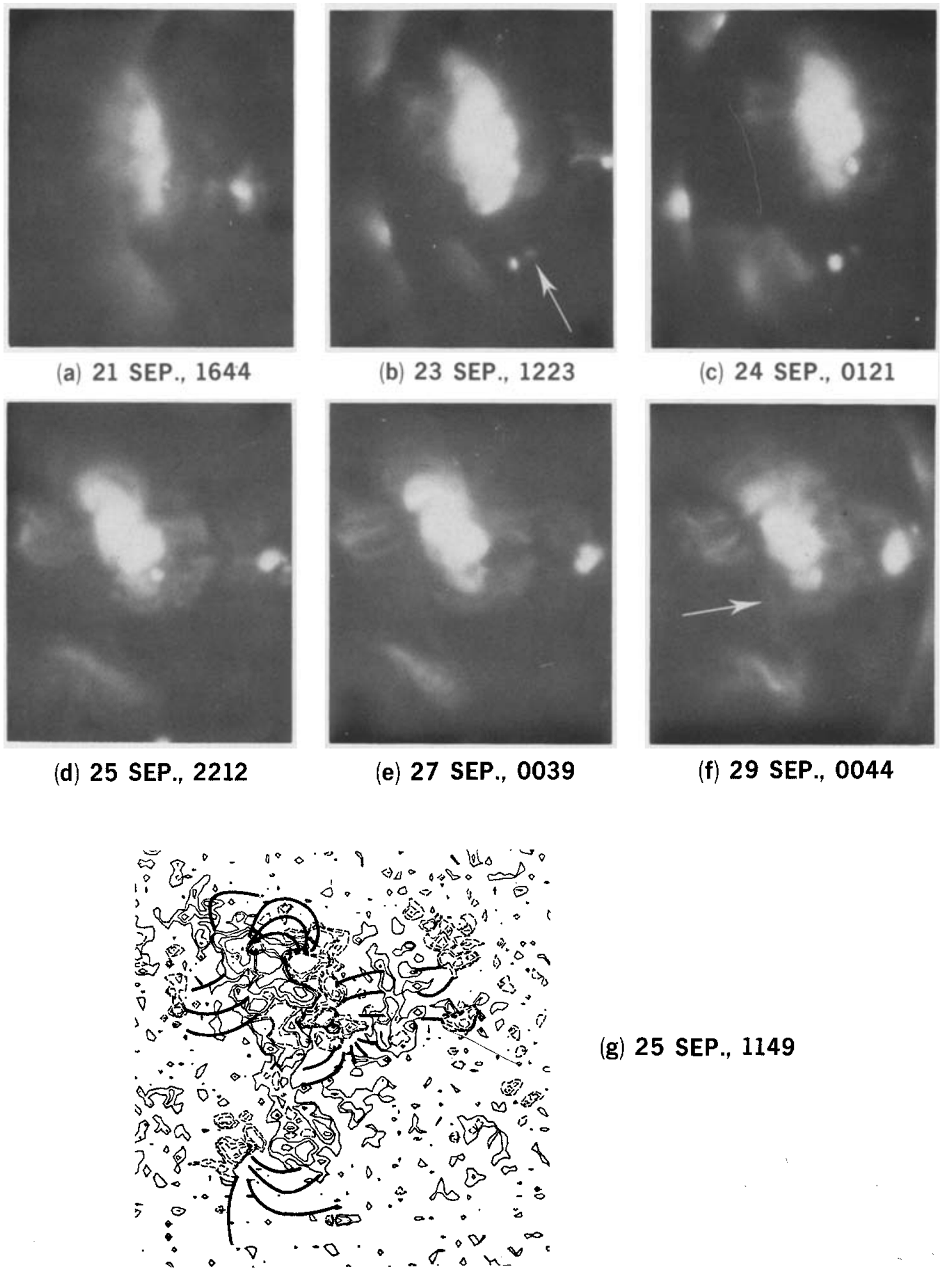


Fig. 7. The complex of activity in rotation No. 1606. Pictures (a), (d), (e), and (f) have been taken through filter 3 with a 16 s exposure. Pictures (b) and (c) are 256 s exposures through filter 1. Picture (g) projects the loops on the Mt. Wilson magnetic map.

7.2. A TRANSEQUATORIAL LOOP

In Figure 7e and 2 one can see an indication of a weak transequatorial connection going from C15p northward. However, one cannot find any opposite magnetic polarity to the north of the equator which might connect with C15p. On September 29 this connection became more distinct (Figure 7f, *cf.* arrow), but even then it was difficult to relate it to the underlying magnetic field. This might indicate that this loop was made up of the chance alignment of shorter loops, and thus was not a transequatorial loop at all. It was the only transequatorial connection indicated during the whole transit in this rotation.

8. Rotation 1607

In this rotation regions C9 and C15 are still clearly visible in the complex, with some loop connections very similar to those in the previous rotation: cf. the S-shaped loop in C15 in Figures 7f and 8a, b, the northern internal loop in C9, and the connection to the remnants of C13. More to the west, the dissolving C1 and C12 merged and decayed after this transit. There were no visible interconnections across the equator and one can suppose that any such connections physically disappeared prior to, or during this rotation: a small coronal hole which first appeared in the previous rotation to the west of the activity complex (cf. Figure 2), began to occupy the space between C9 and C15 on about 25 October. Thus the field lines were opening at the places where the transequatorial loops were before (cf. Section 9.1).

Flare activity of the complex in this rotation was quite small: altogether 5 subflares. Nevertheless, coronal activity similar to that in the preceding rotation still continued in C9, changing the brightness and shape of the northern system of internal loops overlying a filament channel (compare Figures 8a and c). The changes were, however, less impressive than in the rotation before.

9. Rotations 1608 and 1609

In rotation 1608 the activity complex revived for the last time. This revival was due to the birth of a new region C18 (Figure 2) which formed close to the original position of C1 (cf. Figure 1). In the meantime, the merged C1+C12 remnants practically disappeared and regions C9 and C15 greatly dissolved. Still, however, one can distinguish the northern system of internal loops in C9, and the S-type loops in C15 (Figures 8e–g). The coronal hole now occupies the equatorial space between C9+C18 and C15, thus making any transequatorial connections impossible. There were altogether 18 subflares in C18, but all without any impulsive microwave or type III bursts. A small region C19 was born to the south of C18 in the northern hemisphere, but it lived only from November 22 to 24.

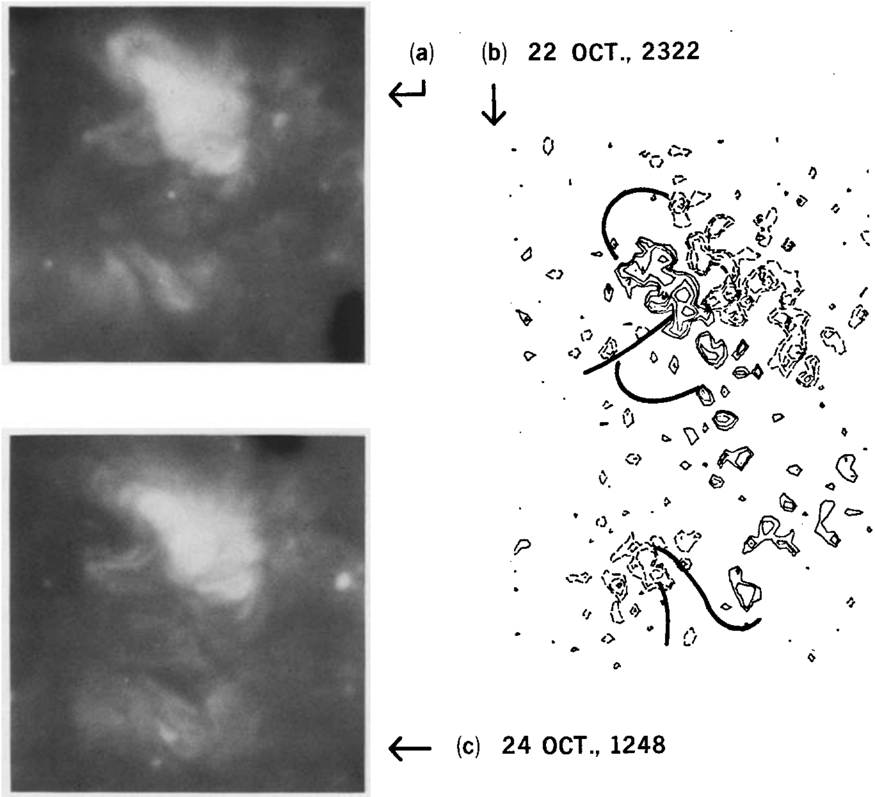
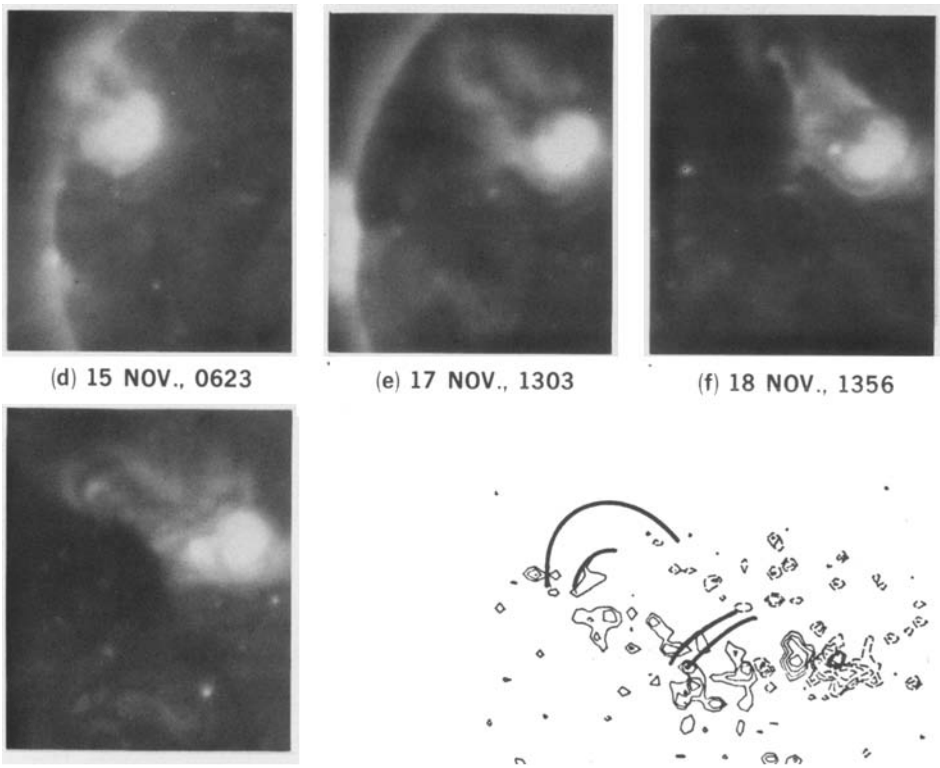


Fig. 8. The complex of activity in rotations No. 1607 and No. 1608. All photographs were taken through filter 3 with 16 s exposure. Pictures (b) and (h) project the loops visible in X-rays on the Mt. Wilson magnetic map.

9.1. A CORONAL HOLE

The coronal hole which was spreading in the west to the equatorial parts of the activity complex was first seen in rotation 1606 (Figures 2 and 9). It began to penetrate into the space of the activity complex after October 25, and extended through the complex quite far to the east in rotation 1608. Unfortunately, we could not see the hole in the next rotation 1609 when the activity complex definitely died, because only X-ray photographs from the hard filter are available for that period.

A rather interesting phenomenon occurred in the morning hours of November 18. Figures 8d and e show the configuration in soft X-rays prior to that date, on the limb and on the disk. One can see the bright core in C18 and toward the east, the extended loops in the old C9; this situation had not changed for several days. Between 0^h20^m and 13^h50^m on November 18, however, *the loops extending along the boundary of the coronal hole collapsed and the hole occupied a great part of the*



(d) 15 NOV., 0623 (e) 17 NOV., 1303 (f) 18 NOV., 1356

(g) ↑ (h) →

20 NOV., 1402

area where the C9-loops extended before. The new configuration can be seen in Figure 8f.

The quality of the unmanned X-ray pictures before 18 November is unfortunately so bad that we cannot trace in detail how the loop system changed. The only conclusion which can be drawn from a comparison of Figures 8e and f is that the southeastern boundary of loops in the filament channel of region C9 was pushed to the northwest thus increasing the coronal hole area.

A comparison with Hα pictures shows that the change in the structure of the X-ray loops was associated with the complete disappearance of the quiescent dark filament which extended throughout region C9. Two subflares were reported in C9 at 05^h23^m in positions very close to the filament channel, so that one can suppose that this was approximately the time of the filament disappearance and of the restructuring of the X-ray loops.

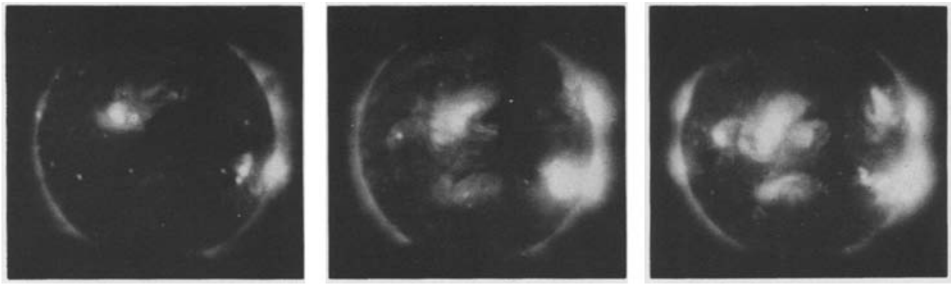


Fig. 9. Longer exposures (64 s through filter 3) show the growth of the coronal hole, which expanded into the region of the activity complex. From left to right: Rotation No. 1606, 27 Sep. 13^h; 1607, 24 Oct. 13^h; 1608, 20 Nov. 14^h.

9.2. Death of the Activity Complex

Region C18 appeared again in rotation 1609, but did not return in the next rotation, 1610, when the complex ceased to exist. The last region possibly belonging to the complex, C20, was born on December 12 in rotation 1609 and died on December 16.

10. The Lifetimes of the Magnetic Interconnections

Table II lists the long-lived connections between different active regions we have identified in the activity complex. For each we give the first date seen, the last time when we could be sure the connection was not visible, the last time seen, and the first time we could not be sure it still existed. The last date, in particular, is very uncertain and some of the interconnections might have existed longer.

TABLE II
List of the most pronounced magnetic interconnections in the complex of activity and their lifetimes

Polarities connected	First seen	Last time not visible	Last seen	First time[a] not visible	Life time (days)
C1p′–C4p[c]	1 July	15 June	29 Aug.	30 Aug.	60 (<76)
C1f–C4f[c]	29 June	15 June	8 Aug.	b	41 (<72)
C1f–C5p	2 July	15 June	11 July	29 July	10 (<44)
C1f–C7p	5 July	4 July	8 Aug.	26 Aug.	35 (<54)
C1f–C9p	23 Aug.	8 Aug.	1 Oct.	17 Oct.	40 (<71)
C4f–C12x[c]	26 Aug.	25 Aug.	29 Aug.	30 Aug.	3 (<5)
C9p–C11f	25 Aug.	8 Aug.	1 Oct.	17 Oct.	38 (<71)
C9f–C13p	26 Aug.	8 Aug.	30 Oct.	15 Nov.	66 (<100)
C9x–C15x[d]	25 Sept.	24 Sept.	1 Oct.	17 Oct.	7 (<24)
C12f–C16p	31 Aug.	30 Aug.	30 Sept.	17 Oct.	31 (<49)

[a] We list the first time we cannot be sure the connection still exists. Weak remnants could exist longer.
[b] Replaced by C4f–C12x on 26 Aug.
[c] Transequatorial connection.
[d] Transequatorial connection?

The table confirms what we mentioned earlier: *whereas the individual loops, visible in X-rays, only live for days or even hours, the magnetic connections in which the loops are seen may have lifetimes of months.* As a matter of fact, Table II shows that the basic magnetic interconnections – the invisible loops – between active regions, once born, live at least as long as both the interconnecting regions exist as distinct magnetic features. It is true that, because of the highly variable visibility on the disk and the complete invisibility for two weeks behind the limb, this interpretation is only a conjecture. It can be that one connection disappears and another is born. However, the interpretation we give is the most reasonable explanation of all the situations we have seen in X-rays during the seven rotations studied.

11. Conclusions

Our first opportunity to observe well a complex of activity in the solar corona has shown us that the earlier description (Bumba and Howard, 1965) of such a complex, which was based on the appearance of surface features, was accurate in describing a complex as a physically interrelated set of active regions. We have seen that the basic components of the activity complex are interconnected through sets of magnetic field lines in the corona which survive for several rotations (Conclusion 2). We suggest that these regions are also connected in some way below the photosphere. This is supported by the observations that there appear to be simultaneous changes over large-scale areas in such a complex of activity (Conclusions 8 and 9), and by the fact that in the later phase of development of the complex the interconnecting loops do not differ significantly in appearance from internal loops in the individual active regions (Conclusion 7). The following specific conclusions may be drawn from the present analysis:

(1) This study confirms that one of the ways (probably the most common way) that interconnecting loops appear is by the emergence of a new active region close to the roots of existing field lines extending outward from old active region fields (Section 4.5). However, at least in one case (Section 6.5) a short interconnecting loop appeared to have been newly formed, within some 12 hours. We did not see any birth of a transequatorial loop (which were all born on the invisible hemisphere), so we could not confirm the earlier result from the case of unrelated active regions (Švestka *et al.*, 1977) that the transequatorial loop resulted from the reconnection of field lines.

(2) The basic magnetic interconnections between active regions, once born, live at least as long as both the interconnecting regions exist as distinct magnetic features (Section 10). On the other hand, individual loops in these interconnections are visible in X-rays only for short periods, typically shorter than 1 day. Some of them may be seen longer, but with changing shape so that we never can be sure that we encounter the same loop (Sections 4.4 and 5.3). Only rarely is a loop seen unchanged for several days, and these are generally loops which connect active regions with very old field remnants (Section 4.9).

(3) Several examples in this and other related studies show that any newly emerging flux tends to make existing loop connections visible (Section 4.5) or brighter (Conclusion 5) in X-rays. Thus we postulate that whereas magnetic connections between opposite polarities in adjacent active regions can exist for months, we see different parts of them as visible X-ray loops only for a short time when new flux emerges (or, more generally, the magnetic field changes) near their foot points (Section 4.7).

(4) There are several examples which suggest fast reconnection of magnetic field lines after new flux emerged from below the photosphere (Sections 4.2, 4.5, 4.9, and 6.2). In some cases the reconnection seems likely, while in other cases (cf. Section 6.2), it is doubtful that the field reconnects. In any case, we do not know whether the field-lines reconnect when the connection is first seen in X-rays, or whether the reconnection occurs only later when the loops brighten strikingly (Conclusion 5). In the case described in Section 6.2 the existing field lines seemed to be only pushed off and deformed by new emerging flux, but still they brightened in an outstanding way, thus indicating that X-ray loops can indeed brighten without any reconnection of magnetic field lines.

(5) Brightenings of interconnecting loops in the complex of activity often show associations with flares, but apparently, at least in the cases we studied, are not caused by them. The flare occurrence and the loop brightening seem to be two different consequences of the same effect: emergence of new magnetic flux (Sections 4.2, 4.4, 4.6, 5.3, 5.8, and 7.1). It may be that the loop brightening in some cases is the visible manifestation of the process of field-line reconnection (Section 4.5, Conclusion 4).

(6) The variability in the shape of loops that can be seen in X-rays can be sometimes directly related to variations in the photospheric magnetic field: growth and shrinking of polarity islands, rotation of the sunspot group (Section 4.7), and migration of polarities (cf. Švestka *et al.*, 1977).

(7) None of the interconnecting loops visible in soft X-rays whose foot points we could identify were rooted in sunspots (Sections 4.2 and 5.4). Their roots are coincident with magnetic hills, but so far as we could determine these hills remained spotless.

(8) In the fully developed complex the interconnecting loops became quite similar in appearance against the disk to the loops internal to the individual active regions (Section 6.5). This emphasizes the physical interrelations of the active regions that constitute a complex of activity.

(9) In one case we saw simultaneous brightenings of several loops in the complex of activity interconnecting its different active regions (Section 4.6). Whereas one cannot exclude a chance coincidence of different sources of brightening, it also offers support for the existence of 'sympathetic' active regions earlier suggested by Fritzová *et al.* (1976).

(10) In one case (Section 5.6) long faint loops reappeared suddenly, extending from an active region to scattered weak opposite polarity fields, which themselves

reappeared suddenly at the same time. It is most likely that the fields and invisible loops (i.e., field lines) existed prior to the sudden reappearance (indeed, they were seen in the previous rotation), and the phenomenon was caused by a change in the nature of the individual magnetic elements, which occurred simultaneously over the large-scale pattern. This change in their nature – perhaps in their field strengths – also caused the loops to become visible.

(11) Interconnecting loops are visible at a variety of altitudes. Some are low-lying, with tops below ~25 000 km (above the photosphere), but in one case an interconnecting loop which did not cross the equator was seen in X-rays extending to an altitude of at least 110 000 km (Section 6.1). Internal X-ray loops in big active regions of this complex of activity generally reached higher altitudes than the interconnecting loops – up to 260 000 km on the limb (Sections 4.3, 5.1, and 6.1). It may be that these differences in height only reflect differences in density and temperature: one needs a certain minimum $(n_e^2 T_e^k)_m$ to make the loop visible in X-rays. This $(n_e^2 T_e^k)_m$ can be reached in active regions at greater altitudes than between them.

(12) There is a possibility that a long straight X-ray feature extending from an expanding and contracting loop in region C12 was the lower part of a transient coronal streamer visible in X-rays.

(13) The X-ray western boundary of C1 assumed a remarkably linear shape in rotation 1604, following the flare of July 29. Evidence for a linear boundary existed during the previous rotation when this boundary was also the magnetic boundary. By rotation 1604, the magnetic fields and plage had grown far to the west, but the X-ray boundary remained unchanged. We presume that the field lines, which remained closed east of the boundary, ceased to connect internally to the region as soon as the migrating root points of the expanding field crossed to the west of this boundary.

(14) Growing and/or brightened X-ray loops can be seen in old active regions quite often also without any associated flare (Sections 5.5, 6.3, and 8). Thus, the absence of any flaring in the chromosphere does not necessarily mean that the overlying coronal active region is quiet and inactive.

(15) The long-lived active region C1 went in soft X-rays through the following distinct phases of development:

(A) Spot-group phase, with X-ray flaring, associated growing loops and loosely associated loop brightenings (Sections 4.2 to 4.6).

(B) Early spotless phase, when filament disappearances produced important flares, with greatly enhanced growing X-ray loops (Section 5.2).

(C) Late spotless phase, when filament disappearances still greatly enhanced the solar corona in X-rays, but the chromospheric response was no more than small brightenings (Section 5.9).

(D) Decay phase, when filaments still were activated, the corona responded with loop brightenings in X-rays, but no brightenings could be recognized in Hα any more (Sections 6.3, 6.6, and 8).

(16) While subflares suspected of accelerating particles occurred in the activity complex already late in rotation 1603, significant enhancement of the particle flux associated with the complex appeared only in rotation 1604. Some sources of particles must have occurred on the invisible hemisphere, since the particle flux was enhanced as soon as the complex emerged from behind the east limb. The major flare of July 29 increased the enhancement substantially, in spite of the fact that spotless flares usually are not significant sites of acceleration processes. The particle flux increased again on 23 August when the complex returned to the east limb in rotation 1605, but it decayed between rotations 1605 and 1606. Thus the complex was active in particle production for about 2.5 rotations.

(17) The final decay of the complex of activity was accompanied by the penetration of a coronal hole into the space where the complex existed before. In one case the coronal hole clearly grew through a collapse of loops in region C9 which was at that time on its boundary (Section 9.1). This collapse was associated with the disappearance of an extensive quiescent filament.

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Note added in proof: A recent chance to see the whole development of the complex of activity in the form of a synoptic X-ray movie (prepared by D. M. Rust and R. Haggerty) has cast more doubt on the interpretation of the spike of 29/30 August (Section 6.4) as a coronal streamer. In spite of the absence of any flaring there was an ejection, and the spike appeared to form the eastern edge of the propagating disturbance (Rust and Švestka, 1977). In another case, detected on August 27, a somewhat similar feature appeared very nearly as a 'spike' for a short time, but it was, in fact, a loop seen briefly edge-on.

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