Abstract

On the basis of the real time records of aurora by use of a highly sensitive TV camera at Syowa Station, Antarctica, classifications of appearance modes, patterns, and dynamics of auroras are attempted. The modes of appearance are classified into continuous appearance and intermittent appearance, patterns into sheet (or discrete arc), diffuse arc, smoke, striation, patch, and surface, and basic dynamics into splitting (or fold-over), fractional rotation, disruption and reconnection, meandering and folding, drift and propagation, on-off switching (or pulsation), and fading out.

Among the 7 dynamical features, the splittings and rotations associated with rapid disruption and reconnections are found to be the most essential ones as the auroral activity proceeds, which leads to both the poleward and westward expansion of dusk aurora and the equatorward and eastward expansion of dawn aurora during an expansion phase.

Rotation and folding-over of bright parts of aurora are concluded to be always clockwise viewed from below (viewed along the magnetic field). For example, splittings arise toward the right-hand side (clockwise curving protrusion from the primary sheet), bright spots rotate clockwise with trailing arms, active bright spots rotate with outward and clockwise streaming arms and small splittings such as ray structures unfold through a clockwise rotation of the split part.

Rotation dominates in the region of a westward travelling surge or auroral bulge and poleward expanding arc, and consequently these regions are characterized by a chain of a strong clockwise vorticity or strong shear of drift, suggesting a rapid production of radial electric field in the magnetic tube of flux corresponding to these regions.

It is pointed out that the clockwise splitting is the initial activation of aurora, and that the split part subsequently expands into a loop or a typical S-type structure as the luminosity increases at the expanding front. On the other hand, another typical pattern, the flame-like pattern, tends to appear mostly at the contracting or shrinking site of auroral activity also as a result of multiple clockwise splittings. It can appear also even at the expanding front when the expansion slows down or stops as well when the expanding front begins to retreat.

An S-type pattern is found to be the most fundamental pattern of discrete aurora at the western part of an activated region, while a flame-like structure is that mostly at the eastern part. The two patterns, despite the apparent difference, are concluded to arise from the same deformation processes, of which the S-pattern formation is an expanding mode and the flame-pattern formation is a less active or shrinking mode. As a matter of fact, rotational symmetry is found between the cusp-like S-pattern formation and flame-pattern formation.

Special emphasis is placed on the striking similarity between the global and local patterns, namely on the fact that the two patterns, the S-pattern and the flame-pattern, are the same independent of the sizes of the patterns from global to local. These essentially have the same development modes, suggesting that the physical processes giving rise to these structures are due to the general dynamics of electron plasma sheet or cloud in a magnetic field without any specific requirments on the configuration and distribution of magnetic field and plasma and that the dynamics is ruled by a simple similarity law which permits a formulations of the dynamics in a dimensionless formula with some appropriate similarity constants.

Inter-relations between auroral activities and VLF-ULF emissions, are briefly reviewed as well.

Introduction

The aurora is an ionospheric projection either of the accelerated electron clouds and beams or of the source region of electrons in the magnetosphere. Thus the aurora is, from another viewpoint, a visual display of an instability or stability of a plasma cloud or beam in a magnetic field which may be related to plasma confinement in accelerator device. Therefore, knowledge about the auroral variation, the mode of appearance and its dynamical characteristics are essential not only in understanding the origin and the dynamics of auroral electrons, and in understanding the acceleration mechanism in interest in space science but also in understanding plasma instabilities in accelerators. Heretofore, however, there have been some limitations on the comprehensive understanding of auroral pattern and its development. For example, the relatively low sensitivity of photographic film has prevented high speed recording of auroral forms, and the observations made from only a single station for the most part have been limited to a small area of the sky even if all sky cameras were used.

As for the former problem, it has been resolved by a new technique, using a high sensitive TV camera developed by DAVIS (1966), making it possible to record auroral forms at the rate of an ordinary TV, that is 60 frames per second. The TV observations have been started in Alaska (DAVIS, 1966; CRESSWELL and DAVIS, 1966) and Canada (SCOURFIELD and PARSONS, 1969a), showing the TV system to be a powerful tool for auroral observation, which has subsequently clarified several interesting characteristic features of aurora, such as flickerings (BEACH *et al.*, 1968), pulsations (CRESSWELL and DAVIS, 1966; SCOURFIELD and PARSONS, 1969 b; SCOURFIELD *et al.*, 1970; SCOURFIELD and PARSONS, 1971a), as well as arc distortions (HALLINAN and DAVIS, 1970) and fast auroral waves (CRESSWELL, 1968; SCOURFIELD and PARSONS, 1971b).

As to the latter problem of relatively limited viewing areas, another new technique has allowed us to view the global pattern of aurora, namely, an auroral imaging technique by use of polar orbiting satellites such as ISIS and DAPP. This has been shown to be an effective technique for obtaining a global pattern, although there still remains some inadequacies; the time required for imaging a frame can be as long as 15 minutes and the time interval between successive photographs can be as long as 1.5 hour. Many examples both of quiet and expanded auroral ovals have been obtained (*e. g.*, LUI and ANGER, 1973; LUI *et al.*, 1973; PIKE and WHALEN, 1974; SNYDER *et al.*, 1974; AKASOFU, 1974) and they have shown that the comprehensive analysis of auroral oval and its development based on all sky photographs by FELDSTEIN (1963) and AKASOFU (1964) are correct as a whole.

The two newly-developed techniques, however, would be much more effective if they were coupled with each other. For example, the weak point of satellite imaging, that is the long time requirement for obtaining a pictures sequence can be compensated by the rapid-imaging, TV system and contrarily the spatial limitation of TV system from ground may be compensated by the coverage of satellites. The complementary nature of the two types of data is realizable from the fact that the auroral dynamics of global and local scales are essentially equal, independent of the sizes, with the characteristic times of deformations almost linearly related to the spatial extent (OGUTI, 1975b). This means that we can find miniatures of almost any dynamics of auroras on a global scale in the local dynamics of small auroral fractions having a very much reduced time scale; in other words, the deformations of global aurora can be inferred from the local auroral deformations. In this connection, the importance of local auroral dynamics obtained by a TV system, to the dynamics of global aurora, can be readily understood.

The purpose of this paper is to classify local auroras mainly on the basis of their dynamics, in order to determine the characteristic dynamical features of aurora which may yield directly the dynamics of auroral electrons both on a local and a global scale, and to present a brief review of the relation between characteristic auroral dynamics and other related phenomena, such as auroral hiss and chorus emissions and magnetic pulsations.

1. Instrumentation

A highly sensitive TV camera, equipped with an SEM tube (MIYASHIRO *et al.*, 1969; SHIROUZU *et al.*, 1970) instead of SEC tube was used. The SEM tube has been shown to be advantageous for use in auroral observations because there is no damage to the target in the case of a severe over-exposure, which often happens when observing auroras due to the wide dynamic range in the luminosity.

Using a lens of f: 1.4, the threshold level of a record is equivalent to about 100 R of white aurora, under the condition of a target high tension of 8 kV, which means that the records includes sub-auroras. We did not use any cooling device for the tube (for both the photo-electric surface and the silicon-target) during this observation period for simplicity. If necessary, therefore, it is possible to attain a much higher sensitivity by use of a higher target voltage and a cooling device for the tube.

A zoom-lens is mounted for objective, but most of the record was obtained by use of a short focal distance, 13 mm, so that the viewing angle of the pictures is about 60° in diagonal. The recording speed was that of an ordinary TV, 60 frames/sec, dispensing with both the slower and faster recording for simplicity. VLF emission, with a frequency range between 100 Hz and 10 kHz, was simultaneously recorded on the sound track of the same video-tape for the sake of accurate comparison between the auroral dynamics and natural electromagnetic waves.

This observation was supplemented by an all sky camera, a meridian scanning photometer for 4278, 5577 and 6300 Å emissions and another scanning photometer for H_β emission of a tilting filter type (FUKUNISHI and TOHMATSU, 1973). About 55 hours video-record was obtained during the observation period from April to October 1971.

All of the TV pictures shown in this paper are those reproduced from the original video-tape thus obtained, with a reduction of sampling rate from 60 to 1, 2, 20 or 21 per second with an exposure time of 1/60 of a second. The center of the frame is almost coincident with the magnetic zenith for observing the small scale aurora with the coordinate axes top and right being to the south (poleward) and to the east, respectively; however, it was changed suitably so that the field of view covers fairly large patterns. The coordinates are indicated in each figure caption, and the common character is that all indicate *southern* *aurora viewed from below*, namely along the magnetic field, so that they are to be compared with *northern aurora viewed from above*. Syowa Station is located at 69°00′S and 39°35′E (−66.7° and 72.5° in corrected magnetic coordinates). The magnetic local time at Syowa Station is almost equal to the universal time and accordingly the time given in UT in each figure can be read as magnetic local time.

2. Classification of Aurora on the Basis of Its Mode of Appearance and Qualitative Characteristics

As should be well known, auroral patterns and dynamics are so complicated that any classification seems hardly possible at a glance. The statistics of many examples arranged with respect to local time, latitudes and the phase of expansion, however, shows that there is a characteristic tendency of appearance of certain kinds of aurora in certain regions for certain stages of activity.

First of all, the modes of appearances of aurora are found to be definitely divided into two groups. The one is the aurora which continuously appears and continuously deforms, and the other is that which appears and disappeares very abruptly and intermittently. Figs. 1* and 2 reproduce typical examples of the two kinds. In the aurora in Fig. 1, in spite of its rapid deformations, both appearance and motions are continuous, while the aurora in Fig. 2 is characterized by an abrupt appearance and also abrupt disappearance of some parts. The latter is a typical example of so called pulsating aurora (CRESSWELL and DAVIS, 1966; SCOURFIELD and PARSONS, 1969), but its variation in luminosity is more aptly called "on-off" switching rather than pulsating because it resembles very much on-off switching of some decorative illuminations of various patterns.

During the quiet stage (without any appreciable expansion), almost every part of the auroral oval consists of aurora of the continuous appearance mode, though there is a difference in nature between the dusk half of the oval which is discrete (sheet) and the dawn half which diffuse and striated. Even when an expansion occurs, the auroras both in the dawn and dusk retain their continuous nature during the initial to main phase of the expansion. Only one apparent exception is ripple or flickering aurora (BEACH *et al.*, 1968) which is often seen in active fold structures, but even the flickering may be a variation of continuous modes which will be discussed later.

During the last phase of an expansion or during the recovery phase, many on-off switching striations and patches appear exclusively in the eastern region at and near the low latitude border of the whole auroral activity mainly from midnight to dawn sectors. The distributions of the continuous mode and on-off

* All figures expect drawings are put at the end of the article.

switching mode auroras as well as typical patterns and dynamics are shown in Fig. 7 in the next section.

Next, our intension is to classify auroras on the basis of the gross features such as, for example, diffuseness, height along the magnetic field line, horizontal patterns and dynamics. This also depends on the local time, latitude and the phase of an expansion. Our tentative classifications are: 1) sheet, 2) diffuse arc, 3) smoke, 4) striations, 5) patch and 6) surface.

The sheet is identical to that called discrete arc by AKASOFU (1974), and is characterized by its thinness, discreteness, its relatively extensive stature along magnetic field and its fold structures as seen in Fig. 1 and in the right-hand (high latitude) side in Fig. 3.

It appears along the dusk half of the oval during a period of no remarkable expansion. The form of its lower border is not straight, but many small splittings and folds appear and disappear even during a very quiet period, which reveal themselves as rayed structures along a sheet. When an expansion occurs, as will be shown later, the sheet rapidly splits and expands into S-type structures in the dusk sectors, which is recognized as an auroral bulge, a westward travelling surge and folds which expand poleward leaving behind many detached auroras.

Although the sheet sometimes extends a little to the dawn side beyond the midnight as it shifts poleward as a whole, the sheet can be said to be the characteristic aurora in the dusk and in the high latitude boundary of the auroral regions.

The diffuse arc is a broad faint arc without any characteristic structures in it as can be seen in the left-hand (low latitude) side in Fig. 3, and is also a typical dusk mode. Under the sensitivity of the present TV system, no diffuse arcs could be found in the dusk during a quiet stage. The diffuse arc always appears in the dusk sector being associated with auroral expansion at midnight; during the main and last phase of an expansion, diffuse arc appears in the region with latitude lower than that of the sheet in the dusk sector. The diffuse arcs are often found adjacent to a sheet at its low latitude side, especially in the main phase of an expansion, but there appears a large gap in latitude between the sheet and diffuse arc during the last phase of an expansion. The diffuse arc may be called as a equatorward expanded remnant in the dusk of an auroral expansion.

The smoke aurora, as we shall call it, looks very much like cigarette smoke, which drifts and rotates, as seen in Fig. 4. Fine structures are often discernible in the smoke but their boundaries are not as clear as that in the sheet aurora. This is, as well as the diffuse arc in the dusk, the expansion-associated form of aurora and is seen both in the dusk and in the dawn. The poleward expanding or westward travelling front of a sheet leaves behind many detached sheet fragments, and they subsequently become smoke. On some occasions, smoke appears in a fairly thick auroral slab when a sheet aurora thickens as the activity increases. Therefore, the smoke aurora is found in and behind the westward travelling surge in the dusk as well as in and behind the poleward expanding sheet in the midnight to dawn mostly during the main phase of an expansion.

The striation aurora looks like a diffuse arc as a whole if the striation structure is not clear, or the striation changes very rapidly. The highly sensitive TV camera with high time resolution, however, clearly shows there are many striations of aurora in the broad arc of this type as seen in Fig. 2. The striation aurora, though sometimes seen in the dusk, essentially is one of the dawn species, and it comprises the dawn half of an auroral oval when auroras are very quiet. This kind of aurora seems to result from both the sheet and smoke through simultaneous multiple splittings and drift splittings. The striations due to a sheet splitting are mostly seen in a quiet fold structure of a sheet in the dusk sector, and that from the lateral drift of smokc aurora are mainly seen in the dawn sector during the main to last phase of an expansion. The striation aurora often exhibits a partial on-off switching variation after a severe expansion in the dawn sector as seen in Fig. 2.

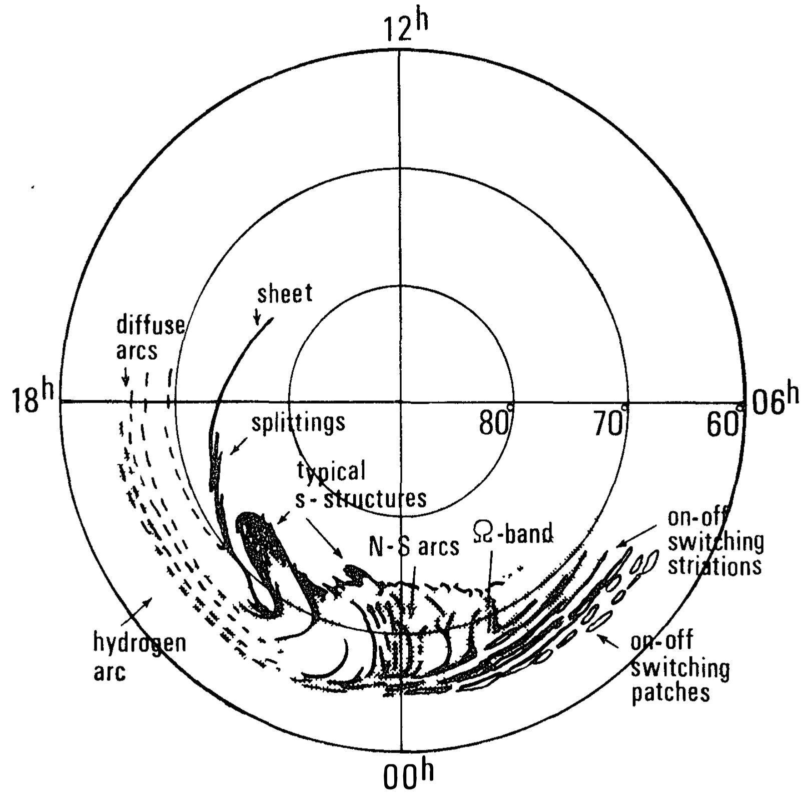


Fig. 7. Statistical distribution of auroras transferred to the northern projection. The sheet aurora is a typical mode in the dusk sector near the high latitude border. The smoke appears near the auroral bulge and poleward expanding front. Surface is seen in the region over which the surge or front swept, and on-off switching striations and patches are the characteristic auroras near the low latitude border of the auroral activity mainly in the dawn sector.

The patch aurora shows, as seen in Fig. 5, a complicated form and is typically observed in the lowermost latitude region of total auroral activity in the dawn sector in the last phase of an expansion to the recovery phase. Most patches usually switch on and off quasi-periodically, with shorter periods at the beginning, gradually becoming longer.

A surface aurora seems to be a transition aurora from sheet and smoke to striations and/or patches during an expansion (Fig. 6). The diffuse arc in the dusk also may be a surface aurora when it expands into a wide latitude range. As seen later, the fading mode of the surface is same as that of on-off switching striations and patches so that they may be classified into the same category. The pictures in Figs. 1 to 6 are typical examples of these six kinds aurora. Their typical distribution patterns are schematically illustrated in Fig. 7.

3. Basic Deformation Modes of Aurora

In spite of the apparent complexity of auroral deformations, some basic deformation modes can be abstracted from the complexity. In doing this, it must be taken into consideration that an auroral pattern and its dynamics may consist of many active regions of a large variety of scale sizes which very much complicates the pattern. Therefore, an attempt was made here to select an auroral form as simple as possible, and to trace how the simple aurora deforms, anticipating that the simple deformation modes deduced from simple auroras, when some of which are combined, may account for the actual complex dynamics.

In this sense, 7 basic modes of deformations were deduced from the actual auroral deformations, such as 1) splitting and folding-over, 2) fractional rotation, 3) disruption and reconnection, 4) meandering and folding, 5) drift and propagation, 6) on-off switching, and 7) fading out.

3.1. Splitting and folding-over

Among six, splitting is the most important deformation, because every activation of aurora is likely to be initiated by splitting. For example, a large-scale splitting along a sheet in the dusk is the initial indication of the development of a westward travelling surge, and a small-scale splitting is the cause of ray structure along a sheet. Striations in the dawn also are due mainly to multiple splittings.

Splittings may be subclassified into two. One type is a simple splitting, and the other is a right-hand curving protrusion of a new sheet. The difference is that the latter is an active mode of splitting and the former is a less active mode. Examples of the simple splitting and of the protrusive splitting are shown in Figs. 8 and 9, respectively. It is not yet clear, whether simple splitting is a variation of the right-hand curving protrusive splitting in which curving is so slight that it seemingly appears as a simple splitting due to the limitation of the spatial resolving power.

An apparently different splitting can be often seen in the striated aurora. Many split arcs or striations appears behind a laterally drifting arc, and this may be called drift splitting. The drift splitting seen in Fig. 10, however, is probably equal to the simple splitting of a sheet, although the split ends are out of the frame in Fig. 10.

Sometimes the split sheet rapidly folds-over in a clockwise direction as seen in Fig. 11. (Throughout this paper, the rotational sense is referred to the direction of magnetic field, so that the rotation is that viewed from below in southern aurora and that viewed from above in northern aurora). This may be understood as a combination of splitting and clockwise rotation.

Splitting often arises along a complexly deformed auroral sheet, which gives rise to a much more complexity in auroral pattern as will be shown later. This type, still, should be classified as a member of the family of splitting. Note that the splitting always appears in a right-hand sense to the primary sheet, namely in clockwise direction. Although the splitting in the reversed sense (in counter-clockwise direction) sometimes seems to appear, it is almost always the result of a clockwise folding-over as seen in Fig. 11, with sharp turning points.

3.2. Fractional rotation

Fractional rotation occurs clockwise around the bright portion of aurora. An example is a curl (HALLINAN and DAVIS, 1966) or trailing rotation (OGUTI, 1974), which appears as a knot along a thin arc or a striation and rotates clockwise as trailing arms or tails.

A trailing rotation is a combination of fractional rotation and very small splittings in the rotating core. It starts along an arc with some irregularities. Irregularities, a little brighter than the other parts begin to rotate clockwise, and subsequently the rotating knots develop into larger scale as seen in Fig. 4, from 234421 to 224425 near the center of the frame. The trailing rotation is found mostly in aurora detached from the main sheet and in a thick slab; accordingly, it is said to be a less active mode of fractional rotation.

An active rotation appears along an active sheet in a different manner as an outward streaming (or leading) rotation. Although the rotational sense of the core is the same, the outward streaming (leading) rotation has arms extending outward in a clockwise sense as shown in Fig. 1, from 005000 to 005006 at the center of the frame, and in Fig. 9 from 235646 to 235651 in larger scale so that the arm connection to the core is reversed from that of the trailing rotation. This may be regarded as a combination of rotation of a bright core with rapid clockwise folding-over around the core.

Rotation occurs not only around really bright parts but also around the center of groups of many bright parts, but the rotational sense is almost always clockwise.

3.3. Disruption and reconnection

A sheet aurora is not easy to visualize in a sketch with one stroke. Some parts detach and reconnect to the other, often leaving many detached sheets after reshaping. The simplest example is a sheet to sheet deformation through disruption-reconnection, which is seen in Fig. 12. A new branch appears due to clockwise folding-over, and it subsequently reconnects to another branch extending from the left, with a disruption of the primary connection.

The essential importance of this mode, however, is the reshaping of auroral forms of both a simple sheet into complicated pattern and vice versa. A typical example is that of sheets split from main arc as shown in Fig. 13. The detachment is found as the result of a reshaping of split parts into a simpler form, leaving behind the protrusive part.

Another example of detachment, the loop detachment shown in Fig. 14 is also a mode of reshaping into a simpler form. As seen in Figs. 13 and 14, a detachment is realized by reconnections of auroral sheets, the main part, of which, reshapes into a simpler form. The inverse role of the disruption-reconnection process, namely the process producing a complicated form, as well, such as S-patterns starting from a simpler form, which will be mentioned later, are seen in the next examples. One is shown in Fig. 15 in which a sheet, initiated by a simple form into an S-structure through splitting, folding-over, disruption and reconnection processes. Accordingly, it should be understood that the disruption-reconnection process reshapes a given pattern into both simpler and more complex forms. It is worth noting that the reshaping is always associated with multiple (or, ideally, a pair of) clockwise splittings, of which, each end point reconnects with each other.

3.4. Drift and propagation

The drift and propagation mode has long been well known, because they are seen in large-scale auroral structures. A typical example of a large scale is the westward drift of sheet fragments split into low latitudes from the main arc system in the dusk sector and the eastward drift of striations and patches in the dawn sector. The eastward propagation of the so called Ω-band may be a member of this family.

This mode, however, is not only characteristic of large-scale auroral forms but also that of small structures as well. For example, a drift of trailing rotational knots along an arc is seen in Fig. 4. Fig. 15, on the other hand, represents the propagation of much more active fold-over structures from 223117.5 to 223118 along the upper sheet with a strong shear of propagation along the sheet. The latter may be called a small Ω-band. Fluttering of an auroral arc shown in Fig. 16 would also be included in this propagation category.

3.5. Meandering and folding

Meandering and folding often appear in the course of splitting or disruption followed by partial unfolding, periodically spaced along a sheet. But on some occasions, they simply result from straight striation or arc, without any recognizable splitting. For example a meandering deformation of a fine striation remnant after the passage of a breakup aurora is seen in Fig. 4 along with trailing rotations.

Another example is a shear folding as seen in Fig. 17 from 224025 to 224027 near the top of the frame. Here again we see a simple shear-like folding of an arc, without splitting. This might be classified into a kind of a protrusive splitting already mentioned or a Caterpiller tread-like expansion of small scale with equal spacing as will be mentioned later. Although the meandering and shear folding have long been believed to mainly be responsible for the auroral fold, they are in reality a less active mode of deformations. The main cause of fold structure is splitting followed by a partial unfolding as mentioned later.

3.6. On-off switching

On-off switching is a category definitely different from the previous 5 kinds. This is not a deformation of auroral forms but is an abrupt and quasi-periodic increase and decrease in luminosity of striations and patches as seen in Fig. 2, the pattern, of which, changes and drifts very slowly. The period of on-off switching ranges from 0.1 seconds up to 10 seconds, and it tends to increase during the repetition of switching. The on-off switching is so rapid as to occur within a fraction of seconds, while the state of on or off lasts longer, a few seconds. The horizontal extent along the oval of a pattern which simultaneously switches on and off often exceeds several hundreds of km. Usually a switch-on region appears at the low latitude boundary of the aurora of this kind, and it propagate successively and intermittently poleward. The repetition of the poleward shift of the switch-on region with period 10 to 30 second, has an extremely close relation to magnetic pulsations which simultaneously occur with a period completely the same as that of the repetition. This pulsation is identical to Ps (OGUTI, 1963) and the associated auroral variation is identical to the auroral coruscation and fluctuation described by CAMPBELL (1961, 1970), and the pulsation of CRESSWELL and DAVIS (1966) and SCOURFIELD and PARSONS (1969). Examples of on-off switching striations and patches are given in Figs. 2 and 5. The characteristics of the on-off switching aurora will be given in more detail in the next chapter.

3.7. Fading out

The fading out modes of aurora can be classified into two. One is detachment fading and the other is worm-eaten fading. The detachment-fading is the continuous fading mode of continuous appearance auroras, especially sheet aurora. When the detached sheet is fairly large, it does not always rapidly fade out, but can remain for a long period of time becoming for example smoke and striations; however, if the detached sheet fragment is small it usually fades out shortly after the detachment. The fading out of the detached sheet sometimes makes the part of main sheet where it detached appear to shrink. Examples of this detachment fading is seen in Figs. 13 and 14.

The other fading mode is the worm-eaten fading. It is the fading mode of surface, on-off switching striations and patches in the dawn. The on-off switching striations and patches disappear after several to a few tens of repetitions, gradually or abruptly, and the region where the aurora faded out appears as a dark hole among the other parts which continue to undergo switching. This form very much resembles a leaf which is worm-eaten when a surface fades out in this manner.

Worm-eaten holes appear abruptly on a surface, and the number and the area of the holes increases leaving veins as striations and patches, as seen in Fig. 6.

Table 1. Elementary deformations and their submodes.

Elementary deformation modes	Submodes
Splitting	Simple splitting Drift splitting Protrusive splitting Folding-over (Eruptive splitting)
Fractional rotation	Leading (or outward streaming) rotation Trailing rotation
Disruption-reconnection	Sheet to sheet deformation Sheet to S-structure S-structure to sheet
Drift and propagation	Westward propagation of trailing rotation and fluttering Eastward propagation of fold-over structures
Meandering and folding	Simple meandering Shear folding
On-off switching	Quasi-periodic switching Quasi-periodic sequential (poleward shifting) switching
Fading out	Detachment fading Worm-eaten fading

Thus we are able to summarize the fundamental deformation modes of aurora as shown in Table 1 and in schematic illustrations in Fig. 18. These elementary processes, combined with each other, consist of actual complex deformations of aurora as shown in the next chapter.

4. Combination Deformation Modes

There are many combination deformation modes as suggested by the actual complicated deformation of aurora. Among the complexities, it is found that the most common dynamics is the formation of fold structure or S-structure in the dusk sector and that of flame-like structure mostly in the dawn sector. Both of them are found to consist of splitting, rotation and disruption-reconnection. Their combination yields a number of varieties of complex deformations.

4.1. S-structure formation

First of all, the important S-structure formations should be emphasized. An S-type structure of auroral arc is a very common feature both in global and in local scales especially in the dusk sector. A fairly large S-structure is recognized as an auroral bulge or a westward travelling surge; a middle-scale S with extent of about 100 km is called a fold; an S-structure as small as several km is a rayed structure of a sheet. Even the global breakup pattern of sheet aurora itself can be regarded as the largest S-structure.

Note that the S of a breakup pattern includes a few S's of travelling surges, which further consist of smaller S-patterns of fold, and further there are a considerable number of ray structures along the sheet fold, each of them being very similar in their geometrical shapes. The striking resemblance between the S-structures of various sizes are shown in Fig. 19; the characteristics of the various S-structure has already been discussed in another paper (OGUTI, 1975b). Thus the S-structure is one of the most fundamental patterns of dusk aurora, especially of the expanding sheet, and, accordingly, understanding the formation processes of the S-structure should be considered as the most basic and essentials of problems in auroral dynamics.

Three kinds of formation processes of an S-structure have been found. The first is a Caterpiller tread-like expansion of a split sheet. At first a sheet splits clockwise and the turning point of the split sheet expand westward and poleward. The expanding front resembles very much a Caterpiller-tread motion of a running tank, tread plates, of which, correspond to the clockwise-rotating, small-rayed structure along the S-pattern. A typical example has already been shown in Fig. 1, from 004955 to 005001; another example is seen in Fig. 27 from 004905 to 004920.

This type sometimes can be recognized as a shear-like folding or a shear-like splitting when the turning point of the primary splitting extends rather than expands.

The second is a combination of folding-over and disruption-reconnection.

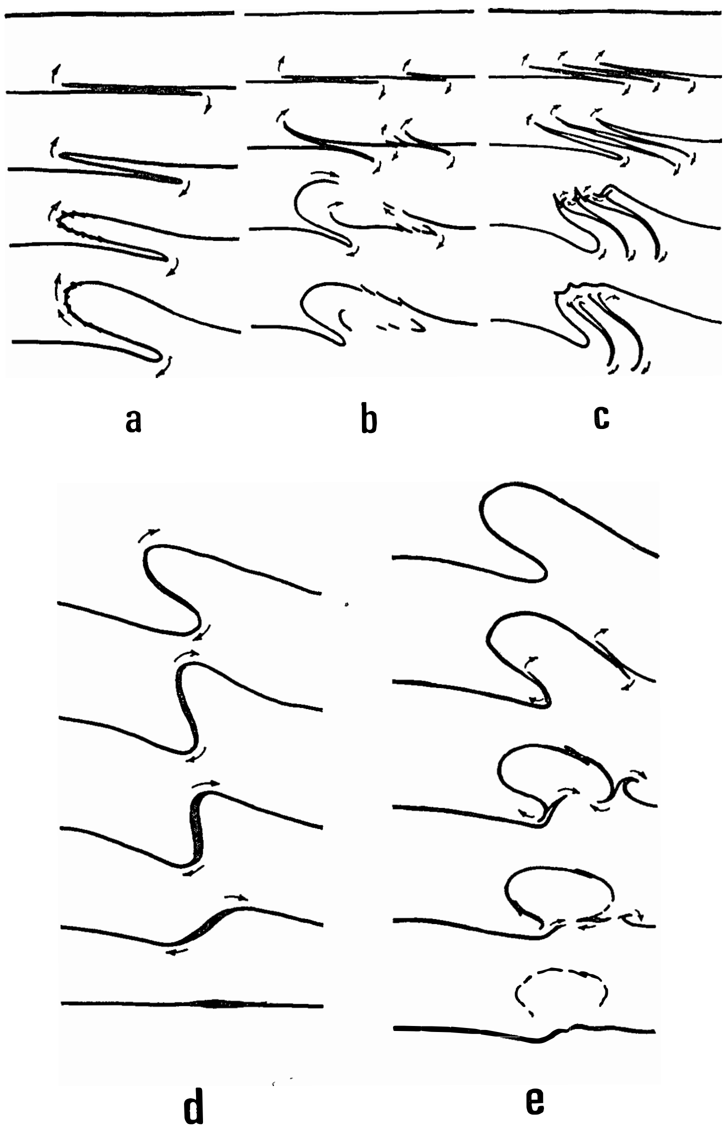


Fig. 20. Schematic illustrations of S-pattern formations (a, b, c) and its releases (d, e).

a) Splitting——Caterpiller tread-like expansion

b) Pair splittings——Folding-over——Reconnection

c) Multiple splittings——Reshaping due to disruption-reconnection processes

d) Rotational unfolding of an S-pattern

e) Release of an S due to loop detachment process

When multiple splitting occurs along a sheet, and one of the splits grows by folding-over clockwise, the end point of the fold-over sheet often reconnects to another sheet split from the right as seen in Fig. 15 from 223117 to 223120 as well as in Fig. 12 from 194429.5 to 194431, leaving detached parts of the initial sheet in the loop of the S-structure.

The third is a combination of multiple splitting and a reshaping due to multiple disruption-reconnections as already seen in Fig. 9 in the previous section as an example of leading rotation or cusp-like expansion. When a multiple splitting occurs along a sheet, the split sheets expands like an accordion stretching as baffles of accordion extend; then, the multiple small splittings appear at the west-poleward ends of each split sheet, which reconnect with each other, reshaping the sheet leaving many detached sheet fragments in a loop of the S-structure.

The examples of S-structure formation in Figs. 1, 9 and 15, in spite of the seeming difference between them, have important common characteristics, namely, all of them are produced by a multiple clockwise splitting and multiple reshaping due to disruption-reconnection. When many small splittings appear and are reshaped successively, the deformation shows a Caterpiller tread-like expansion; when two of the multiple splittings dominate and reconnect with each other, it becomes a combination of folding-over and disruption-reconnection, and when many large split sheets detach due to reshaping it is considered to be third type deformation. All of them are typical combinations of splitting, clockwise rotation, and disruption-reconnection, being essentially alike.

As for the release of the S-structure, we find two modes. One is the rotational unfolding and the other is loop detachment. The rotaional unfolding is a motion which resembles stretching out of a piece of paper previously folded as seen in Fig. 8. The loop detachment is identical to the example in Fig. 14, which is given as an example of disruption-reconnection, and is the inverse process of loop formation in Figs. 1, 9 and 15. Formation and release process of the S-structure thus found are summarized in Fig. 20.

4.2. Varieties of S-structure formations

In addition to the rather simple three modes, there are many varieties of S-structure formations, among which the important ones are the formations of cusp-type S-structure, cusp-reconnection type S-structure, double S-structure and a spiral. All of them are the results of a secondary (and/or a third) splitting in the middle of the primary S-pattern, which subsequently tends to expand or release in a clockwise direction in the same manner that the primary splitting yields the primary S-pattern.

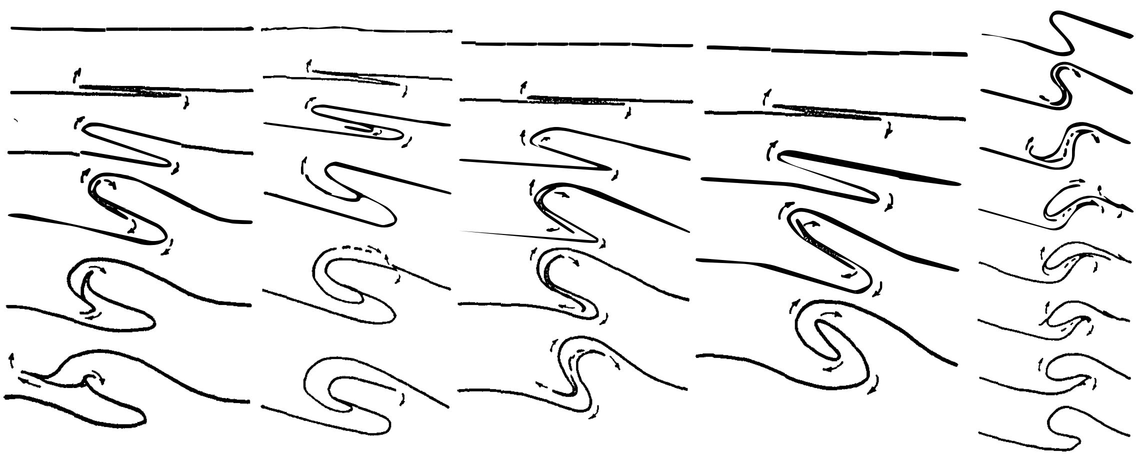
Cusp-type S-structures are frequently seen at the front of westward traveling surges as well as in small deformations of aurora, when the development is in its initial stage: it belongs to the category of the S-structure with a secondary splitting. Secondary splitting arises also in the clockwise direction, along an S-structure previously produced, and the secondary split sheet extends toward west forming a cusp. The cusp is not necessarily single, but is frequently multiple as seen in Figs. 9 and 21. The cusp which is produced from the secondary splitting does not always become extended as seen in Fig. 21, but it sometimes folds-over and reconnects with other branches from the right. This is the cusp-reconnection type S-pattern formation and it yields an S-pattern again, more complicated and more expanded than the initial one as seen in Fig. 17.

When the secondary splitting in the middle of an initial S-pattern neither extends nor reconnects but simply makes the primary S break into two parts, we have a double S-structure as seen in Fig. 22 from 223843 to 223850.

When a second and third splitting occur successively in the middle of an S-structure, the split parts ordinarily rotate and release in clockwise direction yielding a spiral which appears to have a counterclockwise motion. The real motion, however, is always clockwise. This mode resembles very much a clockwise release of a spring previously tightly wound up. This of course does not mean that the original sheet has been really wound up, instead it means that a new splitting appears successively in the middle and the spiral continuously releases in clockwise direction. An example is shown in Fig. 23.

Other varieties of S-structure formation are an outward streaming rotation and ripple (or flickering) aurora. Outward streaming or leading rotation as already seen in Figs. 1 and 9, can be regarded as a combination of a clockwise up-turning and a clockwise rotation and it may be regarded as a kind of a multiple cusp type S-formation. Sometimes it looks like a rotating wind vane. Note that the complicated S-structure formations, in any case, would appear to be an outward streaming rotation if the luminosity of the surrounding parts is much lower than its main part.

The ripple (or "flickering" as denoted by BEACH *et al.*, 1968) aurora as its



a b c d e

Fig. 26. Schematic illustrations of complex deformations of S-pattern. a) Cusp-like S-pattern formation, b) Cusp-reconnection type S-pattern, c) Double S-structure formation, d) Spiral formation, e) S to S deformation.

name implies looks much like a sun beam projected on a wall after being reflected by ripples on a water surface. Although the ripple aurora changes very rapidly in luminosity and pattern so that the exact change in its pattern is hardly traceable, we have some reasons to infer it to be due to small multiple splittings and multiple rotational unfoldings which take place periodically both in space and time. One reason is the fact that the ripple seems to be due to rotations of sheets fragments with extensive field-aligned length (Fig. 25). Such extensive sheet fragments would appear to flicker in luminosity in patches when viewed along the field line as seen in Fig. 24. Ripple almost always appears in a fold structure when multiple splittings of striations develop in the fold. The horizontal scale of a unit patch of ripple aurora is usually less than 10 km, and the period of the rotation ranges from 0.1 up to 1 second, as seen in Figs. 24 and 25. The complex varieties of S-pattern formation are summarized in Fig. 26.

4.3. General feature of S-structure formation

A typical S-structure of course is rotationally symmetric. This means that the forces producing the S-structure development is also rotationally symmetric in an ideal case. However, the S-structure actually deforms into asymmetric forms probably due to the asymetry of the force field. In this case, an S-structure happens to develop preferably in one direction, namely one loop of an S expands while the other does not as has been already shown in Fig. 1, or even shrinks on some occasions, as seen in Fig. 27. The shrinking loop shows an feature definitely different from the S-structure expansion, and a flame structure appears as mentioned in the next section. The discrete S-structure mostly appear in the dusk along the sheet aurora in high latitudes and it usually develops westward, so that the flame pattern often appears along the shrinking loop namely the eastern-low latitude loop of the S-pattern.

Other impressive characteristics of the S-structure formation are, as already noted and shown in Fig. 19, the striking similarity between the small and global auroral S-structures, independent of their sizes and the constancy of characteristic deformation speed which is represented by the characteristic scale divided by the characteristic time. Table 2 shows the typical sizes of and times for produc-

Table 2. Characteristic speed of S- and flame-pattern formaitons.

Pattern	Scale	Time	Formation speed	Remarks
S	3 km	0.4 sec	~8 km/sec	S in Fig. 19, left column
S	30 km	5 sec	~6 km/sec	S in Fig. 1, 004955—005000, and middle column in Fig. 19
S	1000 km	3 min	~6 km/sec	S in Fig. 19, right bottom
Flame	30 km	6 sec	~5 km/sec	Flame in Fig. 27
Flame	60 km	8 sec	~8 km/sec	Flame in Fig. 32, middle picture

ing, a westward travelling surge, fold and ray structures, which indicates the characteristic speed is in a range from 5 km/sec to 8 km/sec. This roughly constant speed suggests that the large scale deformation is due to the accumulation of small scale deformations.

4.4. Flame-structure formation

In contrast to the S-structure formation in the dusk sector, the most fundamental mode in the dawn sector is the flame-structure formation. The flame structure, however, not only appears in the dawn, but also it appears in the dusk.

Just as in the case of the S-structure, there are many scale sizes of the flame-structures. The global flame-structures which are called "torch structures" by AKASOFU (1974) are the largest flame structures, and the smallest flame formation is revealed to be a small folding-over or blaze which resembles the flaming of fire in a dish. There also is a striking similarity of pattern and constancy of the deformation speed between them in spite of the varieties in their sizes. This type of formation is also produced by a combination of multiple splittings and clockwise rotation in a fashion similar to the S-pattern formation, but there is a difference in that the S-pattern formation occurs during an active mode of auroral expansion while the flame structure formation generally occurs for a reduced active mode or the decaying mode. As seen in Fig. 27 the flame-structure frequently appears as an S-structure

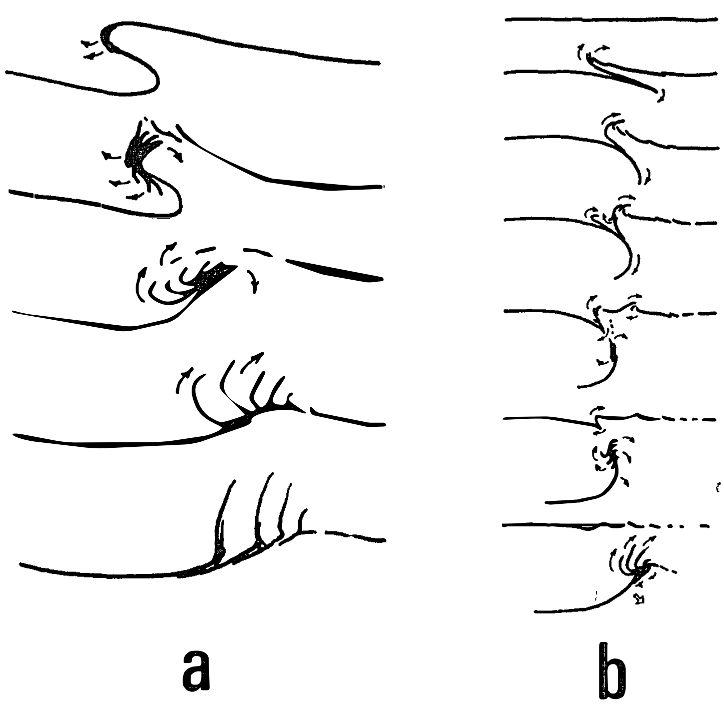


Fig. 28. Schematic illustrations of typical flame-pattern formations.
a) Flame pattern formation through an S-release
b) Flame pattern formation at an end of a detached arc

unfolds or one loop of an S-structure shrinks into a smooth arc as a whole. When the eastern loop of an S-structure unfolds eastward and toward lower latitudes, and the western loop of the same S-structure shrinks eastward also, at the shrinking loop, often appear multiple splittings, which slowly folds-over clockwise. The fold-over sheets grow approximately in the N-S direction and they become flame-structures. The unfolding of an S-structure with eastward drift or rotational release of a spiral with eastward drift which gives rise to a flame structure resembles the growth of a fern frond, of which, the leaves correspond to the blazes of a flame-structure, of which, Fig. 27 is a good example. The flame structure can appear also along a straight arc without a prior S-structure. In this case the flames appear as a result of simple multiple splittings and folding-over as already shown in Fig. 11. These are the main processes for producing global torch structure (AKASOFU, 1974) in the low latitude region of aurora in the dawn.

Flame patterns of this kind often appear also at the poleward expanding front when the expanding speed slows down and stops as a whole; good examples are often seen on DAPP photographs (*e. g.* SNYDER *et al.*, 1973) as well. Two kinds of the flame structure formation are schematically illustrated in Fig. 28. Another kind has already been shown in Figs. 11 and 18c, as an example of the folding over.

4.5. Varieties of flame-structure formation

Although the multiple split sheets result in flame-structures when they fold-over clockwise towards high latitudes as a whole as seen in Figs. 11 and 27, they can be folds of a particular type when the associated folding-over scale is small. A fold structure appears at the shrinking loop or the end point of an arc in a feature that resembles decorative cake lettering made by using a cream squeezer as seen in Fig. 29. This is a variation of flame structure formation when the folding-over is not appreciable as a whole, but is limited to the turning points of the split sheets.

Some outward streaming rotations, which have already been discussed as a whole to be a variety of S-structure formation, can be included also in the flame-structure formation having successive and multiple folding-overs. Especially, when multiple clockwise folding-over occurs at the steep turning point of a sheet, it results in a palm figure each finger, of which, rotates clockwise. This is a typical mode of corona formation as seen in Fig. 30 from 004833 to 004840.

A flame-pattern sometimes appears as an eruptive splitting with many stream lines, when the multiple splitting includes a number of smaller splittings or striations in it. Fig. 31 indicates a typical example of such an eruptive splitting.

Although a great difference of the pattern and its deformation exist both between the "standard" flame-structure in the previous section and its varieties in this section and between modes of the variations, the fundamental deformation mode yielding multiple splittings at the contracting or shrinking site of an arc is common. Note, however, that the eruptive splitting sometimes actually yields a flame pattern at the expansive site not at the shrinking site. Such a case may be preferably classified into multiple protrusive splitting of fine structure.

4.6. Relation between S-structure formation and the flame-structure formation

The growing fern mode of the flame-structure formation is seemingly much different from the S-structure formation in the dusk. The former, however, is found to be rotationally symmetric to the cusp-type S-structure formation. It can easily be shown that the two patterns are the same if the growing fern type flame pattern is rotated by 180° and compared with the cusp-type S-structure. For example, the middle and bottom pictures in Fig. 32 are flame patterns, the bottom being identical to that in Fig. 27; here, however, they are put upside down, and the top picture shows a typical cusp type S-structure reproduced from DAPP photographs (Pike and Wahlen, 1974). The essential similarity is readily found between them, namely, not only between cusp and flame but also between global and local patterns.

This indicates that the flame-structure appears as the cusps of an S-structure, depending on the direction of the expansion, and it develops into flame-structure as an S-structure unfolds or shrinks. The flame structure, in this sense, is a remnant left behind by moving or releasing S-structures, especially at the shrinking or unfolding site of an S-structure.

This fact indicates that a flame-structure turns towards low latitudes when an S-structure develops and unfolds toward the west, and contrary to this the flame appears as a flaming-up toward higher latitudes when an S-structure expand and unfolds in the eastward direction. The global auroral pattern seen by DAPP supports this conclusion.

More generally, it may be said that when a reshaping effect dominates after the multiple splitting has occurred, it tends to result in an S-pattern, while the many split sheets which respectively fold-over without a remarkable reshaping after the multiple splitting yield the flame-patterns. The reshaping effect is activity dependent, being dominant in the active phase at the rapidly expanding front while becoming less effective as the activity decreases especially at the contracting or shrinking part of aurora.

4.7. Other rotation dominant combination deformations

N-S directed arcs, often found in the dusk to midnight region during a main phase of an expansion, can be understood in terms of arcs splitting and detaching from the main, poleward expanding, sheet, which rotate clockwise as a whole as they drift westward slowly. The detaching ends of the arcs often tend to be flame-structures and the end points drift eastward while the initially split ends drift westward undergoing a slow clockwise rotation of the arcs themselves as seen in Figs. 18g and in 28b. The N-S directed arcs can be said, therefore, to be large flame structures. The initially split ends of the arcs drift down to lower latitudes and they halt at a certain latitude becoming the striation arcs in the dawn sector, which, shortly thereafter, sometimes changes into on-off switching striations.

Trailing rotations sometimes appear quite abruptly propagating along an arc. In that case the appearance very much resembles that of a solar flare as seen in Fig. 33. This sometimes happens to be classified as a fluttering mode as already mentioned.

4.8. Varieties of drifting or propagating aurora

Although the N-S directed arc and the drifting rotational knot have been referred to previously as rotation dominant examples of the combination of splitting, drift and clockwise rotation, they may also be regarded as variations of the drifting mode. In addition to them, here in this section, several other varieties of drifting or propagating modes are exemplified. Among them, the westward propagation of the S-pattern which is frequently associated with the rotational unfolding, the eastward propagation of the fold-over which is a variation of flame-structure formation, and the poleward shift of on-off switching striations are the most remarkable.

Westward propagation of an S-pattern can be realized by the same process for yielding the S-pattern itself. New splittings appear and are reshaped continually and successively at the front of the western and higher latitude loop of the S-pattern making the loop expand westward, while the eastern and lower latitude loop shrinks sometimes leaving behind detached sheets or folds. When the westward propagation is accompanied by a rotational unfolding, as it very often is in actual deformations, the combined motion appears like a fluttering of aurora as already seen in Fig. 16.

The eastward propagation of a fold-over structure is, as already mentioned, a common feature of aurora at its poleward boundary, regardless of whether it is a striated arc or sheet. The eastward propagation of the fold-over frequently is a western counterpart of the eastern S-structure of a larger S-formation process. As a matter of fact, the fold-over which arises in the eastern part of the activity, as already shown in Fig. 15, reconnects to the other branch from the right yielding an S-pattern, as it propagates eastward. In this sense, the eastward propagation of the fold-over structure may be a variation of the flame-structure formation. Both the small folding-over and global torch or Ω-bands propagate eastward in this process.

The other typical combination, the quasi-periodic poleward shift of switch-on region along with eastward drift is a dawn mode of variations. There appear some active patches along the low latitude boundary of the striation aurora in the dawn after an auroral expansion. The active patches abruptly appear and disappear repeatedly as they slowly drift eastward as well as slowly change in pattern. The on-switching of the patches appears to cause the on-switching of the striations located adjacent in higher latitudes, and the switch-on state seems to propagate successively (in a statistical sense) to the striations in higher latitudes. As the switch-on state propagates poleward, the switch-off state follows. Accordingly a bright belt seems to shift. However, it is not really a continuous shift, but is due to an abrupt change of switching-on regions, as seen in Fig. 34.

Propagation occurs not only for the deformation pattern but also for a bright part. Luminous parts sometimes propagate to and fro along a thin sheet very rapidly ($\sim$100 km/sec) as seen in Fig. 35. After the propagation of the bright parts, there usually appear small scale splittings, striated obliquely to the original arc. The saw-tooth structure thus produced appears to release into a sheet through an unfolding process similar to that shown in Fig. 8.

In addition to the four modes mentioned above, one more drifting mode is noted here. This is a peculiar irregular drift of smoke aurora, which appears just behind an expansion front, especially when the poleward expansion comes to a pause. The smoke auroras drift irregularly, and the drifting direction as well as its speed changes irregularly. An example of this type is shown in Fig. 36.

4.9. Varieties of on-off switching auroras

Although some on-off switching auroras appear at a glance to be quite irreg-

Table 3. Typical combination deformations.

S-pattern formation	Splitting — Caterpiller tread-like expansion
	Splitting — Pair folding over — Reconnection
	Multiple splitting — Reshaping into S
S-pattern release	Rotational unfolding
	Loop detachment
S-pattern deformations	Splitting in the middle — Folding over — Cusp-like expansion
	Splitting in the middle — Folding over — Reconnection into S again
	Splitting in the middle — Double S-pattern
	Splitting in the middle — Partial unfolding — Spiral pattern
	(Palm structure formation)
	(Eruptive splitting)
Flame-pattern formation	S-pattern release — Torch like-structure
	— Cake decoration lettering
	Multiple folding over
	Eruptive splitting
	Palm-structure formation
Variations of rotation dominant mode	Ripple (flickering) aurora
	Trailing rotations of flaring mode
Variations of drift and propagation mode	Eastward propagation of fold-over structure
	Westward propagation of S-pattern
	Quasi-periodic sequential poleward propagation
	Propagation of bright spots along an arc
	Irregular drift
Variations of on-off switching aurora	(Quasi-periodic sequential poleward propagation)
	Flaming aurora
	Swinging aurora
	Chorus associated diffuse switching patches
	Surface aurora

ular, there is a statistical tendency to propagate poleward starting near the lowermost latitude boundary of the auroral activity, an example of which has already been shown in Fig. 34 as an example of the propagating mode. The example in Fig. 37 is also a variation of on-off switching aurora. Some auroral patterns appear to be generated in a certain region and they also expand poleward abruptly and intermittently. This quasi-periodic shift of the switch-on region repeats itself 10 to several tens of cycles with a repetition period of about 10 to 30 seconds, while the pattern itself, when it is switched on, drifts and deforms very slowly, so that we see repeated appearances of nearly the same patterns so long as the quasi-periodic propagation period lasts. Fig. 38 also shows the same kind aurora; here the repetition is much more rapid than that of the example in Fig. 37. In this case, the deformation of the whole pattern resembles the undulations of a water plant in a brook.

When the on-off switching aurora is seen in E-W direction near the horizon, it resembles flaming up of a blaze with rapid oscillations as in Fig. 39. This type may be identical to that identified as flaming aurora.

During late morning hours after an auroral expansion, many faint, diffuse patches rapidly switch on and off repeatedly, as seen in Fig. 40. These rapidly varying diffuse patches are almost always associated with strong chorus emissions. The varieties of the combination deformations are summarized in Table 3.

5. Relation between the Local Dynamics and Global Dynamics of Aurora

As already mentioned in some of the previous sections, the dynamics of continuous mode aurora is independent of the scale of the activation region. The global breakup auroral pattern is almost the same as the smaller activation patterns which consist of a small S-structure in its western part and a flame structure in its eastern part. In addition to this, it has been pointed out that the formation processes of the S-pattern is the same to that of the flame pattern. This means that the fundamental deformation processes of aurora are essentially the same regardless of the difference in local time and latitudes, and to the direction of the primary arc as well. The differences of the S-structure and the flame structure are ascribable to the differences in the regions of activation and the stages of activation of the particular structure under consideration. However, on the other hand, as the global pattern shows, there are differences, probably not substantial but apparent, between dusk-high latitude aurora and the dawn low latitude aurora. The most remarkable differences are in the diffuseness and in the continuity of the appearance, namely, the former is always a discrete sheet of the continuous mode, and the latter consists of somewhat diffuse, switching striations. In addition, two points can be mentioned. One point is that while a clear global S-structure propagating westward is found in the high latitude side in the dusk, no clear global S-structure propagating eastward has ever been found in the low latitude side in the dawn which should be expected to exist if the rotational symmetry holds on a global scale. Another difference, which may be complementary to the first, is that the flame structure such as a torch in the dawn is directed poleward but there is no flame-structure in the dusk directed equatorward.

These differences may be accounted for by taking into consideration the following facts: 1) the magnetic field configuration in the polar cap and that in lower latitudes is very much different from each other, namely, the lower latitude field may acts as a wall which dams up the aurora from shifting toward lower latitudes, while that in high latitudes does not, 2) the general electric field could largely affect the rotational symmetry for such a large pattern as global breakup pattern, 3) accelerated and trapped particles as the products of an expansion also could modify the pattern, 4) the diffuseness of aurora is very much dependent on latitudes, being discrete at the high latitude border while it becomes diffuse as it departs from the border into lower latitudes, and 5) the discrete sheet aurora may be regarded to appear around the close-open boundary of the magnetic field while the switching aurora likely to appear in the closed field region.

The difference between diffuse arc in the dusk which originally is a flame structure developing equatorward and bounded along a constant L-shell and the flame structure being directed poleward in the dawn may be the effect of the magnetic configurations mentioned above. The dawn to dusk general electric field also should interact with the electron aurora typically manifested by the S-structure because the general electric fields affect and alterate the symmetry of the forces. In this connection it is meaningful that the region of strong H_β emission propagates eastward in the dawn, suggesting positive potential production in the dawn. This may correspond to the intensification of downward field aligned current (Zmuda and Armstrong, 1974) in this region. The region of proton precipitation may have an inverted S-structure, also distorted, in the dawn at its eastward expanding front as indicated by Fukunishi (1973), although it is not very clear mainly due to a large scattering. It is noteworthy that the electron aurora tends to be an S-pattern, while the hydrogen aurora probably tends to be an inverted S-pattern during an actively expanding phase, viewed

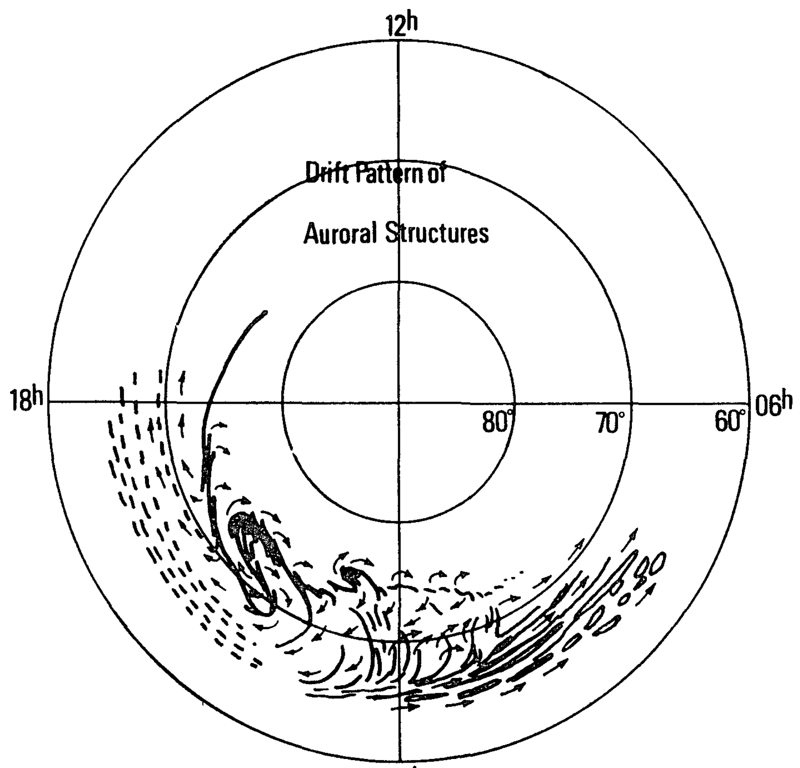


Fig. 41. A schematic illustration of drifting patterns of auroral structures based on TV observation.

along magnetic field.

Another point of importance to be noted here is the global auroral expansion consisting of smaller S-pattern formations. This is that the travelling surge as well as poleward expanding sheet does not continuously expand westward and poleward. The expansion arises intermittently and stepwisely when and where a fairly large S-pattern newly appears along the sheet aurora, and the local intermittent and stepwise expansion which successively appears from place to place along the sheet results in the westward and poleward expansion of sheet aurora a as whole during the breakup phase. This corresponds to the stepwise magnetic substorms reported by ROSTOKER (1974).

Summarizing the dynamic features of the electron auroras, we are able to draw a composite map of drifting auroral structures. Fig. 41 shows the drifting pattern of auroral structures with respect to the global breakup pattern. As seen in this figure, the typical dynamical feature of aurora in the lower latitude area in the dusk is the westward drift associated with the slow clockwise rotation of auroral arcs detached from the main sheet in higher latitudes. This motion results in an equatorward shift of arcs when the auroral arc position is monitored in the meridian line. In the region bounded by the westward travelling surge, poleward expanding sheets, and the pre-existing hydrogen arc before expansion, the rotation of arcs is fairly remarkable so that in some instances during the course of breakup, all arcs in this region have N-S direction.

Along the most active regions of S-patterns such as the westward travelling surge (or bulge) and the poleward expanding arc, rotational characteristics dominate, designated as the active fold-over or high vorticity. This region includes varieties of typical rotational motion and it is, in a sense, a chain of vortices, which therefore suggests that it is a strong shear line of auroral drift.

Near the eastern end of the high vorticity region, rapid rotations or fold-over of sheet fragments occur during breakup yielding small flame structures especially at the poleward and eastward expanding front of the H_β region. The motion makes an auroral sheet decay into sheet fragments.

In the dawn sector, a flame-structure develops as a result of multiple splittings followed by clockwise rotations and folding-over at the poleward boundary of the striation arcs. Ω-bands and torch-structures (AKASOFU, 1974) are thus produced and drift eastward. Note that the drift of on-off switching striations and patches, which appear at or near the low latitude border of the striation arc in the dawn is also eastward. This means that, in a fairly wide range of latitudes, the drift of auroral structures is eastward in the dawn, except the very narrow westward region due to the small scale rotation along the high latitude sheet. Thus a definite reversal of drift along the dawn auroral oval could not be found. Where or whether can we find the zone of drift reversals corresponding to the electric field reversals observed by satellites and ion cloud release (*e. g.* HEPPNER, 1973; HAERENDEL, 1973; MAYNARD, 1974) is further open to question. Contrary to this the sheet aurora in the dusk sector is found to be a definite line of drift shear, which just corresponds to the electric field reversals observed by satellites and ion cloud release (*e. g.* FRANK and GURNETT, 1971; HEPPNER, 1973; HAERENDEL, 1973; MAYNARD, 1974; GURNETT and FRANK, 1973).

The so called Harang discontinuity (HEPPER, 1972; MAYNARD, 1974) in the region dusk to midnight is probably identical to a well developed S-structure, where the rotational characteristics of auroral forms dominate. Because if thc rotations is related to the electric field, the strong shear of drift along the main part of a developcd S-structure should be identical to the reversed current patterns in this region and the electric field converging to the main part of the S-pattern.

6. Relation between Auroral Dynamics and Associated Phenomena

Since BURTON and BOARDMAN (1933) found the relation between auroral display and VLF hiss emission, many efforts have been devoted to find the mechanism of auroral hiss emissions, and statistical relations have thus become quite clear (*e. g.* ELLIS, 1959; HARANG and LARSEN, 1965; JØRGENSEN, 1966; HIRASAWA and KAMINUMA, 1970; KOKUBUN *et al.*, 1972).

However, the relation has long been not more than statistical in rigorous meaning, because the low sensitivity of auroral recording prevented us from high speed recording of auroral patterns, corresponding to rapid variation of hiss intensity. The highly sensitive TV camera has for the first time made it possible to research the peak to peak relation between auroral and auroral hiss emission.

Auroral hiss is generally associated with the rapidly splitting and rotating, small, but bright sheet structures. As seen in the example of Fig. 42, the simultaneity between increase in luminosity of a small auroral sheet fragments and the spike-like hiss enhancement holds within a few tens of milliseconds with correlation coefficient between them usually higher than 0.8 (OGUTI, 1975a). Contrary to this, even when aurora is fairly luminous, it may not be associated with hiss emission if it is a quiet form. This fact suggests that a rapid increase in precipitation in small extent and the rapid change in the position of the small precipitation region of the auroral electrons acts collectively as an electron cloud, so that Čerenkov emission (ELLIS, 1957; JØRGENSEN, 1968) is emitted with good coherency. However, there are some other alternative possibilities and the definite causality of the hiss associated with aurora is still an open question. In any case, the fact to be accounted for is that hiss is a typical phenomenon associated with sheet aurora as it partially brightens and rapidly moves and not any other.

Auroral chorus emission is found associated with a rapid on-off switching of faint, sometimes subvisual striations and patches in the dawn sectors as shown in an example in Fig. 40. The periodicity of the appearance of the chorus group and that of auroral switching is statistically similar to each other, but one-to-one correspondence between a certain chorus and an abrupt brightening of a certain patch has not yet been found. The reason for the difficulty in identification arises first because of the difference in the spatial extents of observations of chorus and

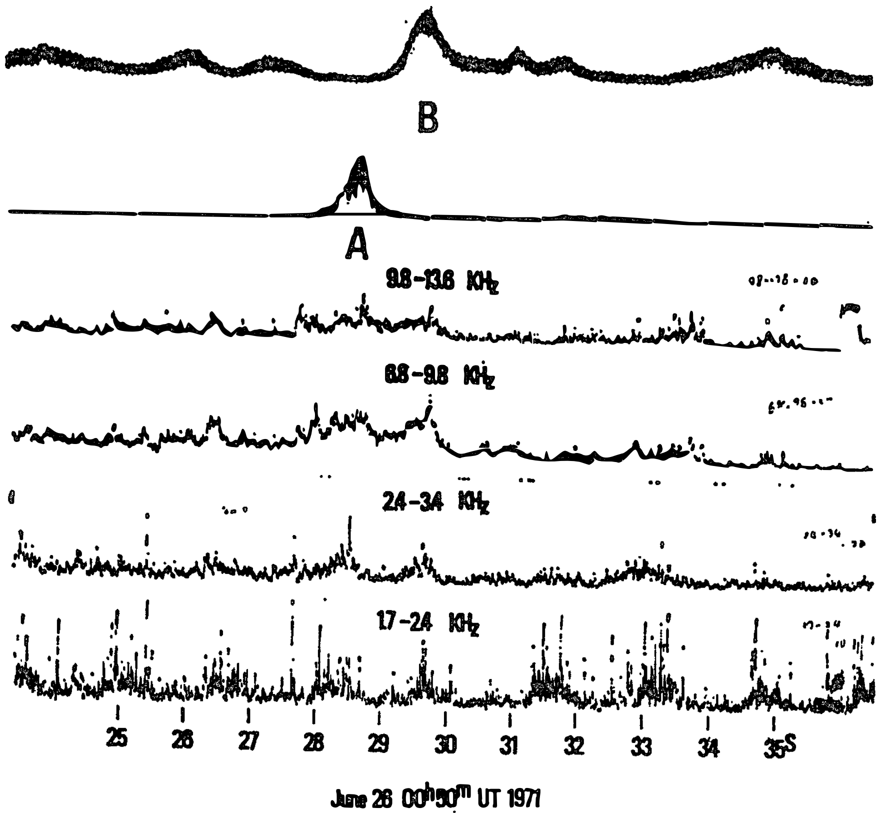


Fig. 42. Relation between the temporal variation of luminosities of small sheet fragments (two curves in the top) and those of hiss intensities (bottom four curves). The high coherency of these variations indicates that the auroral parts designated here as A and B are the hiss emitting activities.

aurora, namely, the former covers an extended area whereas the latter views only a small portion of the sky, and secondly because of the fact that the electrons act as backward oscillators for emitting chorus possibly giving rise to an appreciable time difference between arrivals of the waves and the corresponding particles.

The quasi-periodic on-off switching aurora in the dawn has already been shown to be closely related to the geomagnetic pulsations of period of about 10 seconds (OGUTI, 1963). This is identical to the auroral fluctuations associated with geomagnetic pulsations reported by CAMPBELL (1970). By use of the TV technique, it is readily confirmed that the magnetic pulsation is synchronized with the quasi-periodic poleward sequential switching of auroral striations and patches, and that the fluctuation of auroral luminosity so far observed by a fixed photometer was due to a quasi-periodic poleward passage of the on-off switching aurora at the observation area. Two possibilities leading to the synchronous relation are considered. One is the magnetic modulation of pitch angle of energetic electrons due to the compressional component of hydromagnetic waves in the magnetosphere, and the other is accounted for in terms of the modulation of the ionospheric conductivity due to the pulsative precipitation of energetic electrons under a given electric field. A definite conclusion requires further investigation.

Since we have found extremely good correlations between the on-off switching auroral patches and the appearance of chorus emissions, and that between the quasi-periodic poleward propagation of the on-off switching auroras and the synchronous geomagnetic pulsations with period from 10 to 30 seconds, it is understandable that there exists also a good correlation between a chorus group (Q-P emission, HELLIWELL, 1965) and geomagnetic pulsations. As a matter of fact, HAYASHI and KOKUBUN (1971) and SATO *et al.* (1974) have clearly shown that there are some geomagnetic pulsations associated with quasi-periodic enhancement of chorus emissions. This may be identical to VLF emission pulsations studied by CARSON *et al.* (1965) and auroral zone emissions centered at 700 cycles per second reported by EGELAND *et al.* (1965).

Owing to the high sensitivity of our TV system, we were thus able to show that the chorus is associated with the rapid on-off switching of faint auroral patches in the dawn, and that geomagnetic pulsations are synchronously associated with quasi-periodic poleward propagation of the on-off switching auroral group each member, of which, probably corresponds to each chorus emission.

Concluding Remarks

We have shown that the auroral dynamics can be abstracted into some basic deformation modes, which, combined with each other give rise to a complex deformations of actual aurora. Among them, the clockwise splitting or right-hand curving extension, clockwise rotation, disruption and reconnection should be taken to be the most fundamental and essential for producing the most characteristic S- and flame-patterns of aurora. In this connection, five important points are

1) that the auroral activation is almost always initiated by clockwise splitting or right-hand curving extension of a new sheet, split from the primary,

2) that the rotation is always clockwise viewed along magnetic field,

3) that the modes of typical S- and flame-structure formation are the same independent of the sizes,

4) that the S-structure formation and the flame-structure formation is essentially the same relative to their rotational symmetry,

5) and that the deformation speed, represented by the characteristic scale divided by the characteristic time is almost constant, several km per second, independent of the sizes.

In addition to these, as for associated phenomena we found

6) that the VLF hiss emissions are synchronously associated with a rapid brightenning and rapid motions of small portions of sheet auroras,

7) that the VLF chorus emission is associated with rapid on-off switching of faint patches in the dawn sector,

8) and that the geomagnetic pulsation with period from 10 to 30 seconds is synchronously associated with the quasi-periodic poleward propagation of the on-off switching auroral group.

The rotation of the auroral form, is always clockwise, and the rotation speed statistically increases as luminosity increases. Furthermore, as mentioned already, there is a striking similarity both of patterns and of deformation modes of aurora, whatever the size of an auroral activation, from a global breakup pattern to a small-scale pleat of sheet aurora such as ray structure, and wherever local activation occurs. These facts indicate that the physical reason of the characteristic deformation is common for both the global aurora and the local aurora. The precipitation of auroral electrons, is possibly related to the converging electric field due to the negative charge excess produced in the magnetosphere, to which the upward field aligned current (ZMUDA and ARMSTRONG, 1974) are probably related. As a matter of fact, the small scale auroral deformations seem to be interpretable in terms of several instability mechanisms associated with a converging electric field. For example, the sheet beam instability (HALLINAN and DAVIS, 1970; WEBSTER and HALLINAN, 1973) or Kelvin-Helmholz instability would account for the trailing rotations as for point 2.

The important points here, however, is the S-pattern and flame-pattern formations with a constant deformation speed. This indicates that the clockwise splitting is the essential mode of activation and that there should exist some similarity laws independent of the scales. According to the formulation of dynamics of charged particles in a magnetic field, (*e. g.* LEHNERT, 1964), the dynamics can be described in a dimensionless formula if the two characteristic numbers $k_1=mL/qAt$ and $k_2=t\phi/AL$ are conserved, where L, m, ϕ, A and t are a characteristic scale length, mass of the particles, electric potential, magnetic vector potential and time, respectively. The constant deformation speed indicates the vector potential, and accordingly the scalar potential are both conserved. Thus, the electric potential at the center of a characteristic auroral patterns of various scales is an important point as for the constant deformation speed.

A question arises here as to whether the auroral pattern seen at the ionospheric level can be traced back into the magnetosphere. This concerns where the deformation of auroral electrons takes place, namely in the source region or along the transit path. The fact that an S-structure can be produced for as short time as 0.4 second, if it is as small as 3 km, suggests that the deformation can be considered to arise along transit path from the source region to the auroral ionosphere. On the other hand, a large S-structure such as the westward travelling surge with a characteristic scale length of 1000 km, can hardly be regarded to have no effect on the source region. As a matter of fact, many satellite observations clearly shows that remarkable variations in particle flux appear in the magnetosphere beyond the plasmapause (CHAPPELL, 1974) especially in the dusk sector where the typical S-patterns (westward travelling surge) are frequently seen. Although the plasma clouds outside the plasmapause are widely believed to be those detached from the plasmasphere, rather they might be products associated with the auroral bulge or S-structures.

The fact that the rapid formation process of a small pattern within a fraction of second, which is shorter than the electron transit time, is the same as the slow process yielding a large pattern, which obviously should have some sort of influence on the magnetospheric structure, also suggests that the deformation of aurora must be due to a general and universal dynamics of the electron sheet or cloud in the magnetic field without any requirement on the primary configuration of the magnetic field (closed or open) and on the plasma distribution (in or outside the plasma sheet). However, we do not yet know what actually is the pattern of electron fluxes in the magnetosphere corresponding to the S-pattern at the ionospheric level, and this is still open to question.

Next we consider the clockwise splitting or right-hand curving extension of a sheet at the beginning of activiation. Since an eloectron cloud is a system essentially having a clockwise momentum as a whole, any acceleration should deflect its motion into the right-hand side. Therefore, if some irregularities exist or are newly-produced along a sheet, and the irregularities undergo an acceleration, the magnitude of which depends on the nature of the irregularities, new sheets would expectedly extend into the right-hand side of the direction of the acceleration. This motion may cause the clockwise splitting of an original sheet. However, this by no means claims no importance of current induced instabilities such as helical instability (HASEGAWA, 1971). Instead, the development of auroral patterns may be due to the successive propagations of helical instability regions, since rapid deformations of aurora are always associated with field aligned sheet currents.

In concluding, we should like to make a remark on the similarity between the pattern of solar flares observed in H_α emission and that of aurora. Although we do not yet understand the true physical mechanism producing S-structures of electron aurora, if the S-structure formation is intrinsic to the electron cloud resulting from its clockwise momentum, and if so is the inverted S-structure for the proton cloud viewed along the magnetic field, the pattern and development of the H_α region of a solar flare, associated with a sunspot with a known magnetic polarity, may be useful for investigating the plasma behaviour near sunspots.

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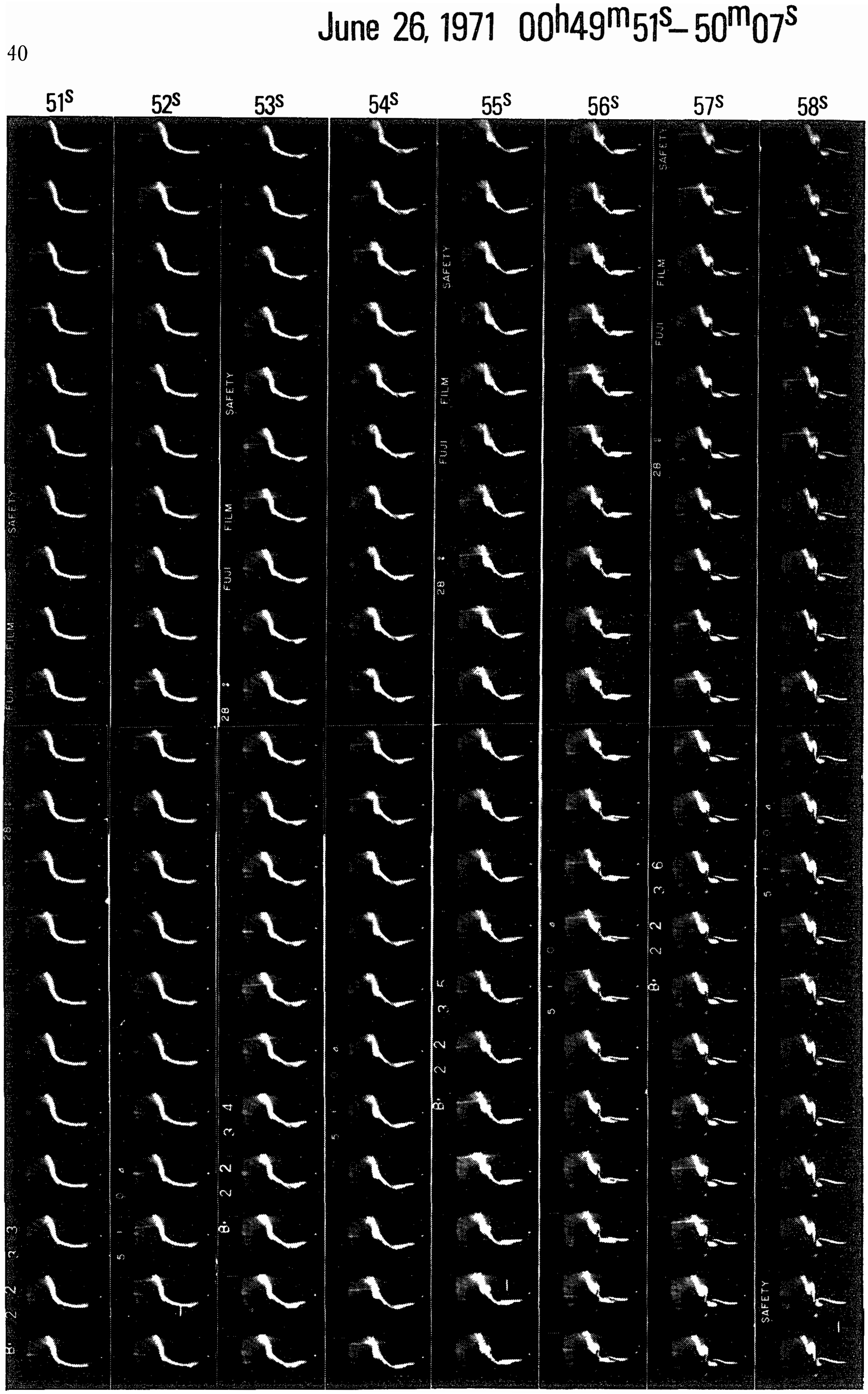


Fig. 1–1

Fig. 1. *An example of continuous mode aurora. This is also an example of sheet type aurora. The center of the frame is approximately coincident to the magnetic zenith. Top is to the magnetic south and right is to the east. The aperture angle is about 60 degrees in diagonal. The aurora is a poleward expanding front during an auroral breakup. A splitting begins at 55.0 sec, and it↗*

Fig. 1-2

↘*expands into a loop like a Caterpiller-tread of a running tank at 56.7 sec, near the center of each frame. Leading rotation of an auroral fragment which shows outward streaming rotation also near the center of the frame is seen from 004959.9 to 005006.0.*

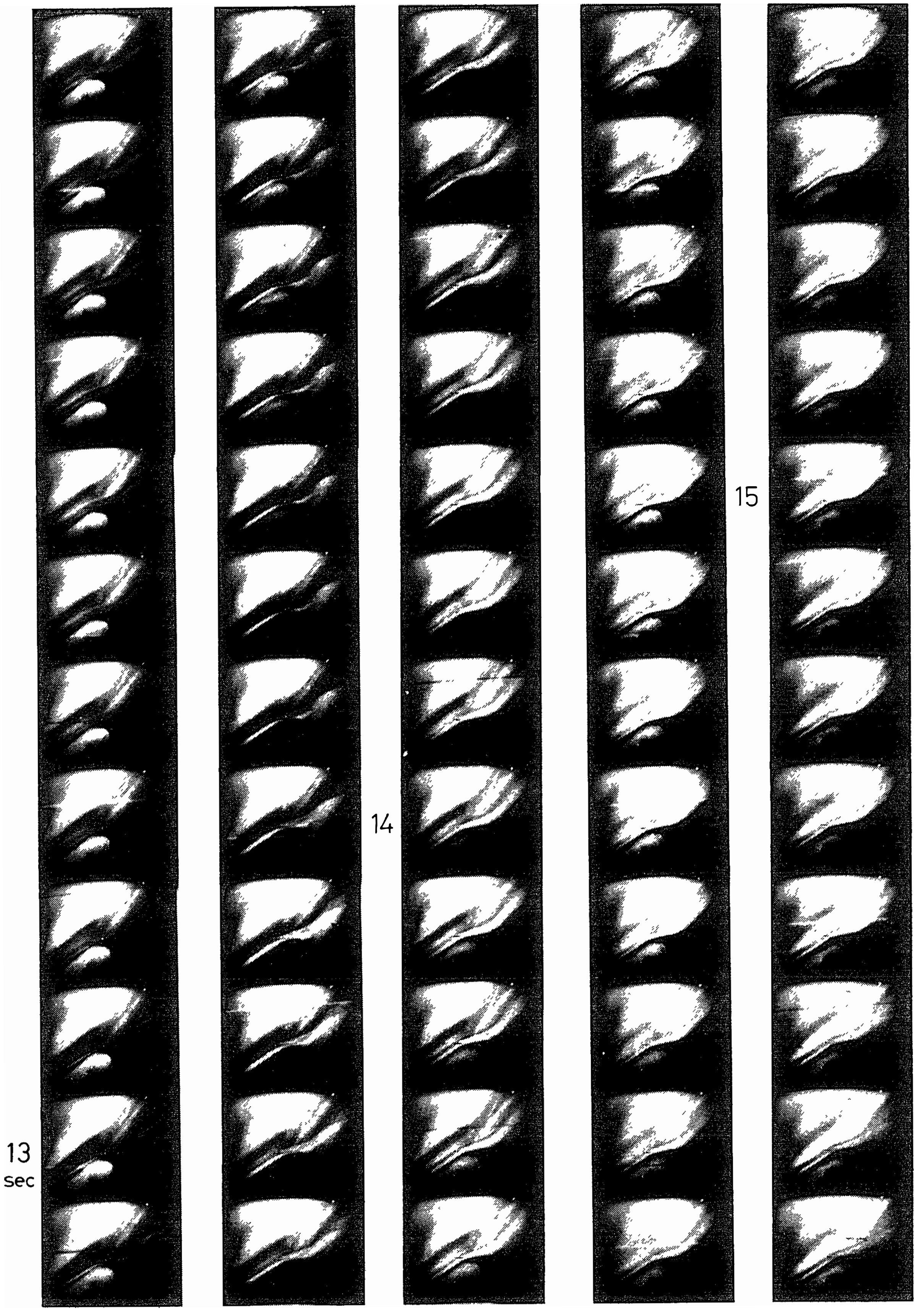


Fig 2-1

Fig. 2. An example of on-off switching striations. The center of the frame is magnetic N-W near zenith.↗

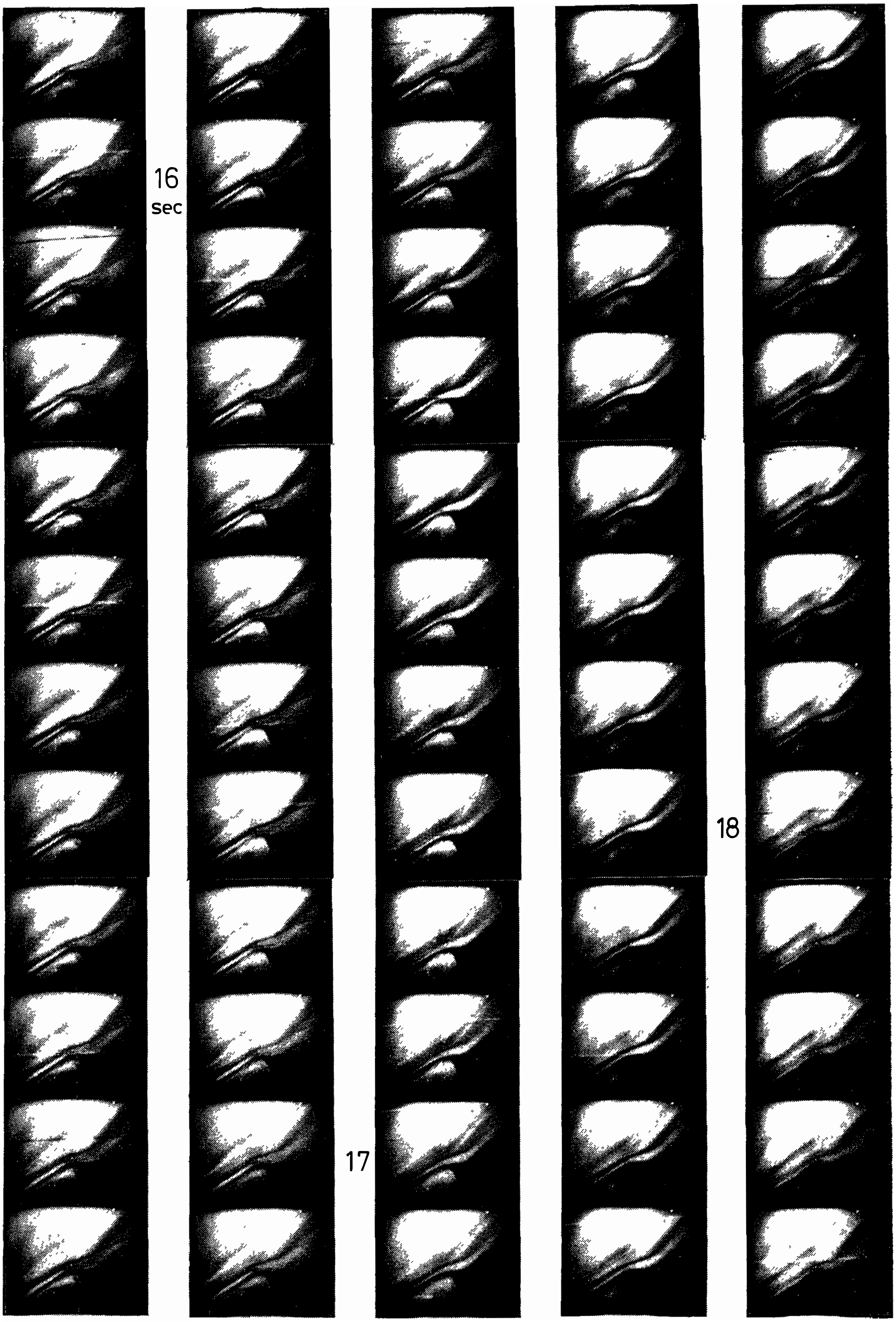


Fig. 2–2

↘*Top is to the magnetic S–E and right is to the magnetic N–E. This is a typical on-off switching aurora which appears near the low latitude boundary of the auroral activity in the dawn sector after an auroral expansion. Fine striations switch on and off quasi-periodically.*

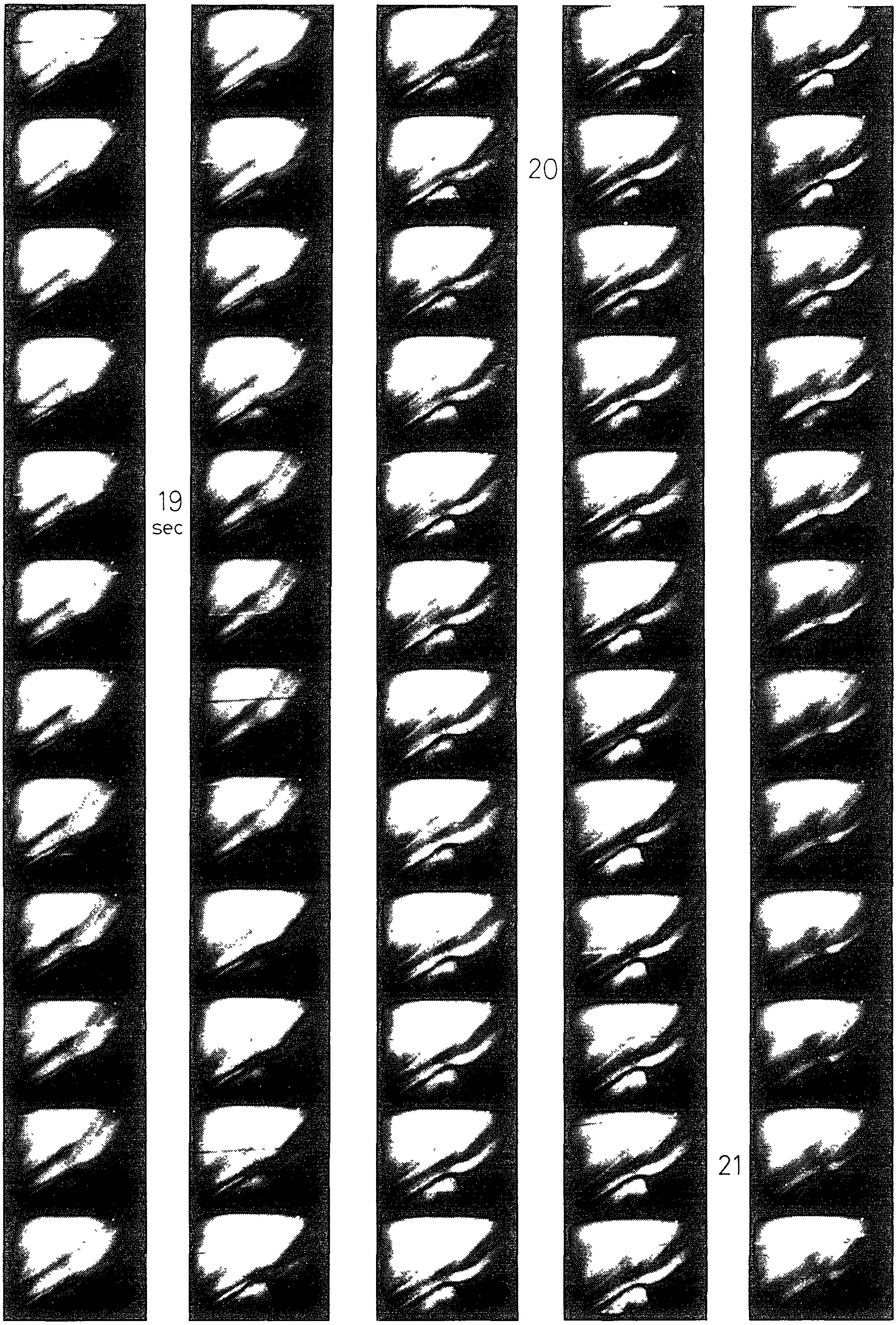


Fig. 2–3

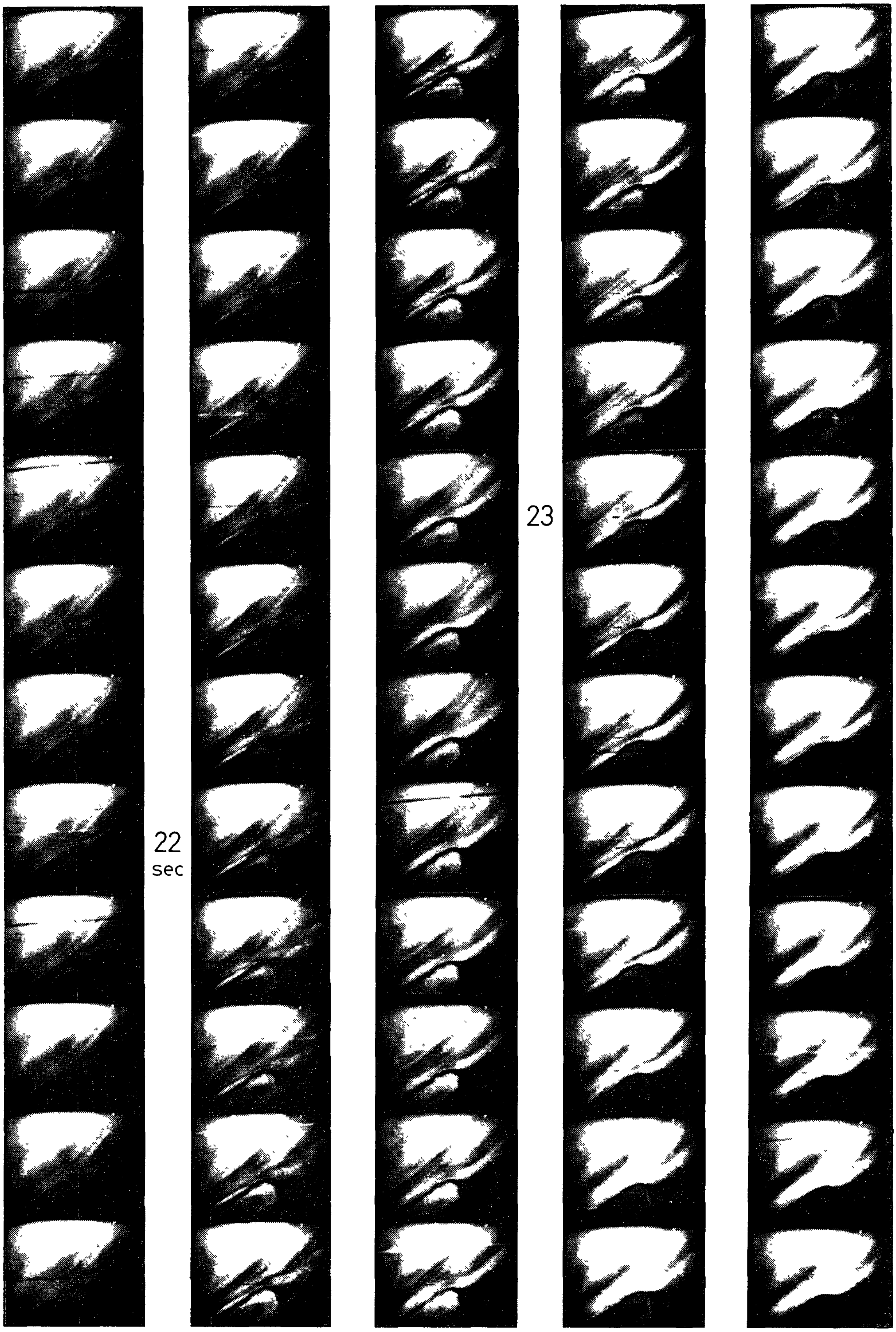


Fig. 2–4

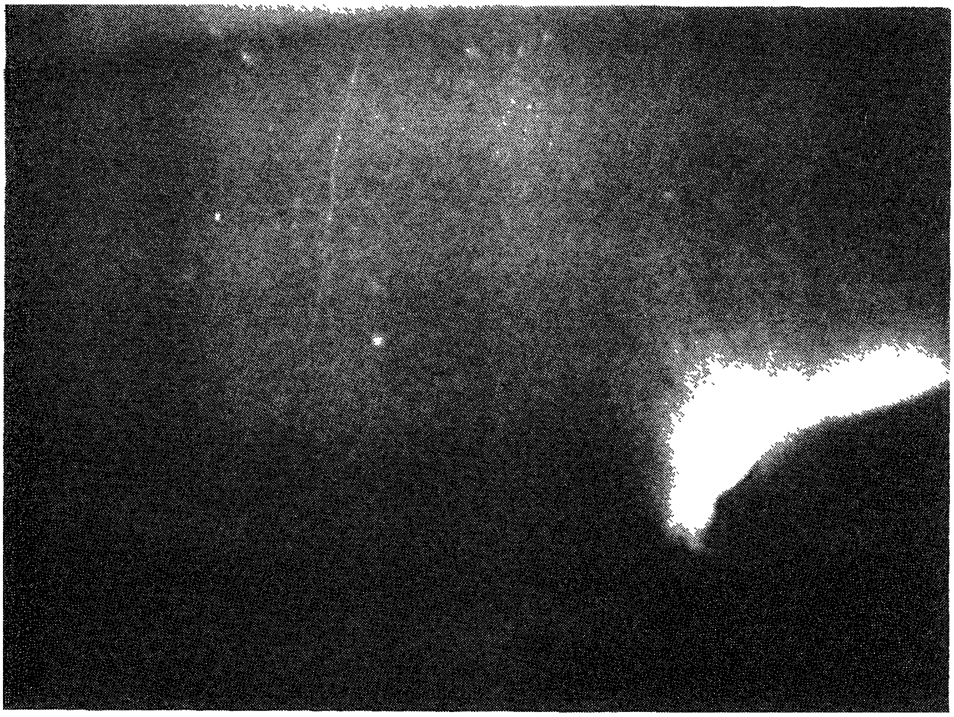
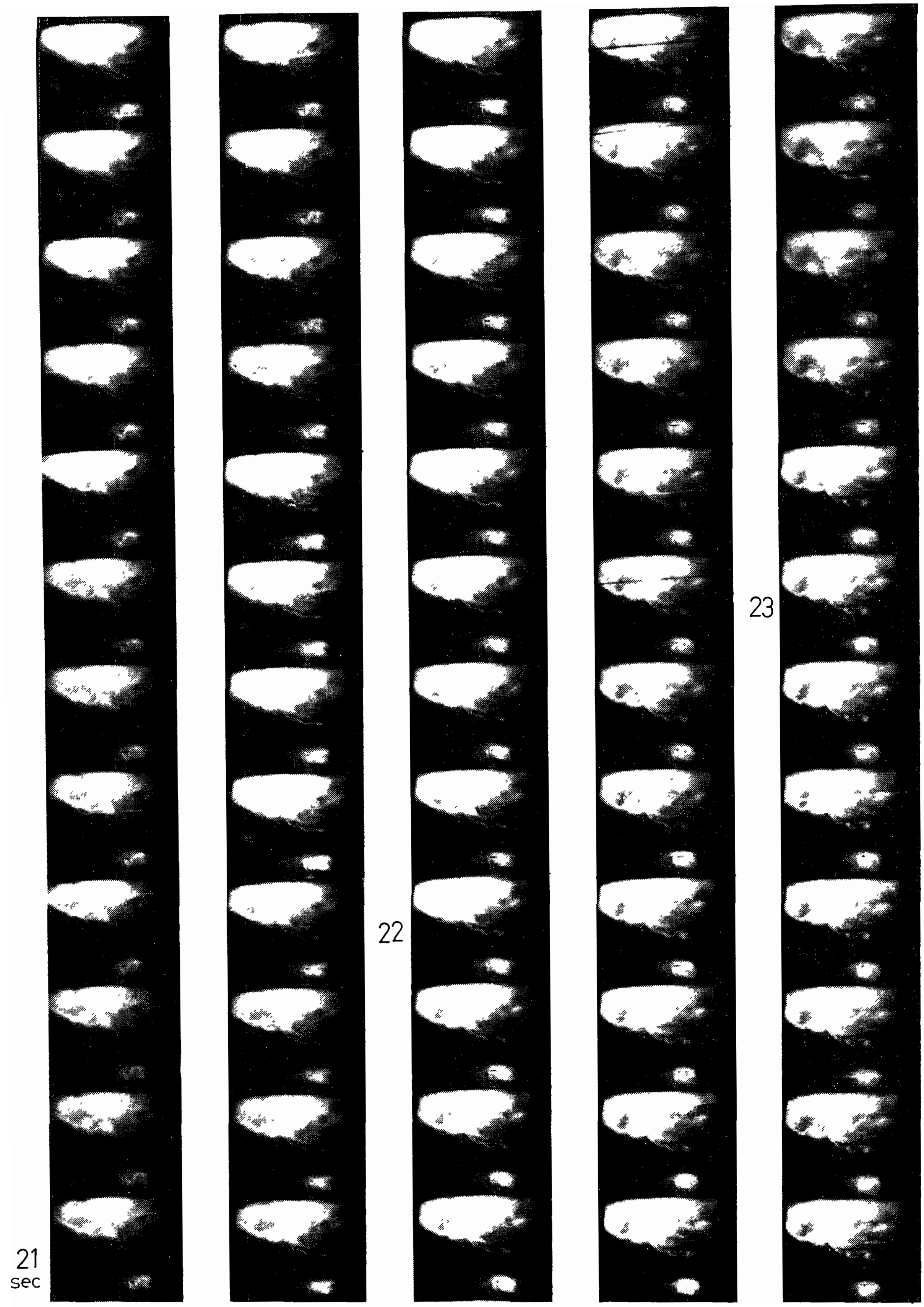


Fig. 3. Sheet (right-hand side) and diffuse arc (left-hand side) auroras. Magnetic east near horizon. Top is to the magnetic west and right is to the south.



AUG. 25, 1971, 23 44 21-23 44 29 UT

Fig. 4-1

Fig. 4. A typical example of smoke aurora. Formations of trailing rotations along an arc are seen from 21.0 sec to 26.0 sec near the center of the frame, which propagate to the left-hand side along the arc.↗

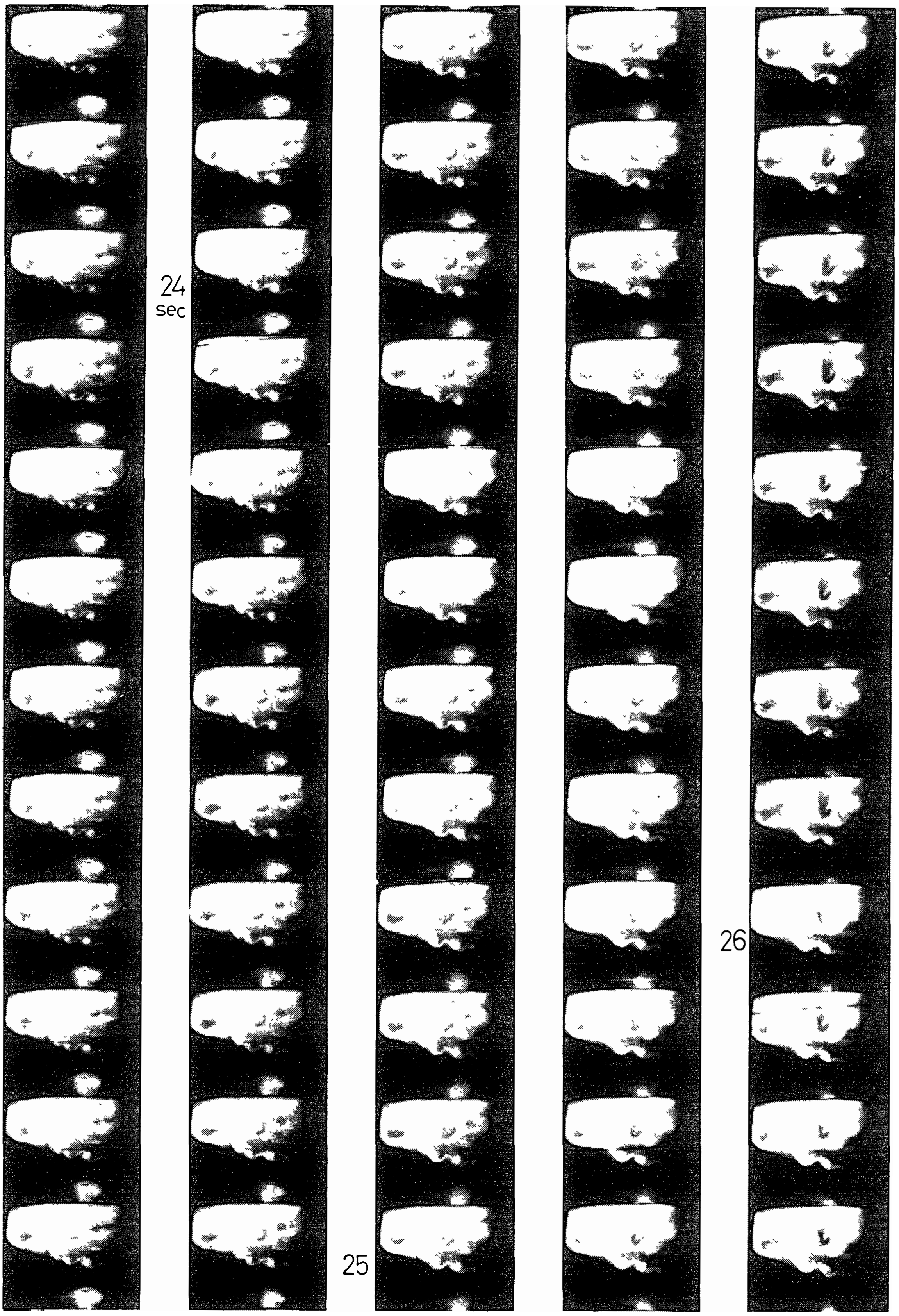


Fig. 4–2

↘*The arc finally tends to meander at about 27 sec. Another meandering of arc is seen from 23 to 24 sec slightly above of the primary. The center of the frame is approximately coincident to magnetic zenith. Top is to the magnetic south and right is to the east. This kind of aurora appears in and*↗

Fig. 4–3

↘*near the westward travelling surge (or bulge) and the poleward expanding front mostly behind them during an auroral expansion.*

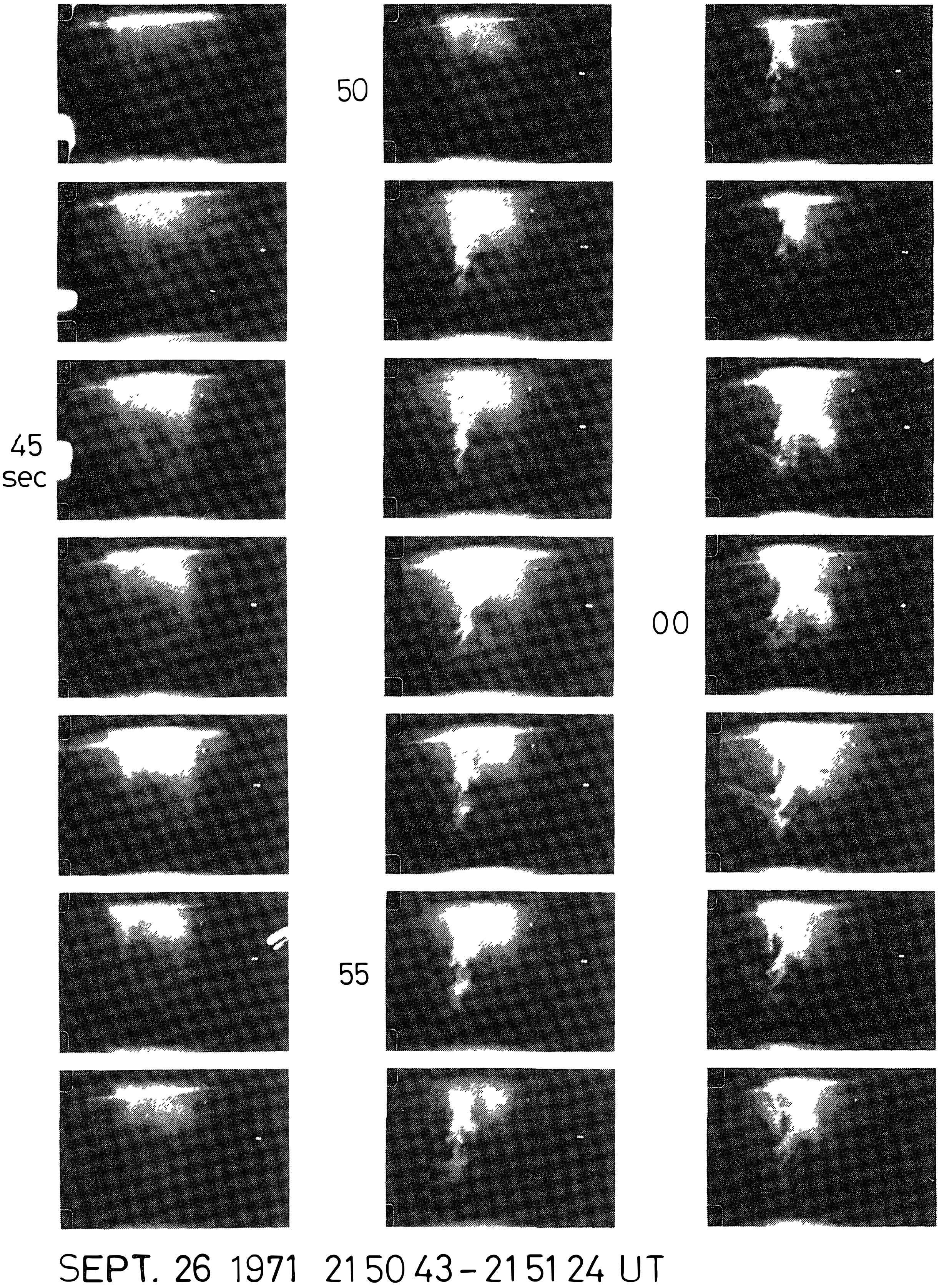


Fig 5-1

Fig. 5. A typical example of on-off switching patches. Complicated patches switch on and off quasi-periodically. The center of the frame is approximately to the magnetic zenith. Top is to the magnetic↗

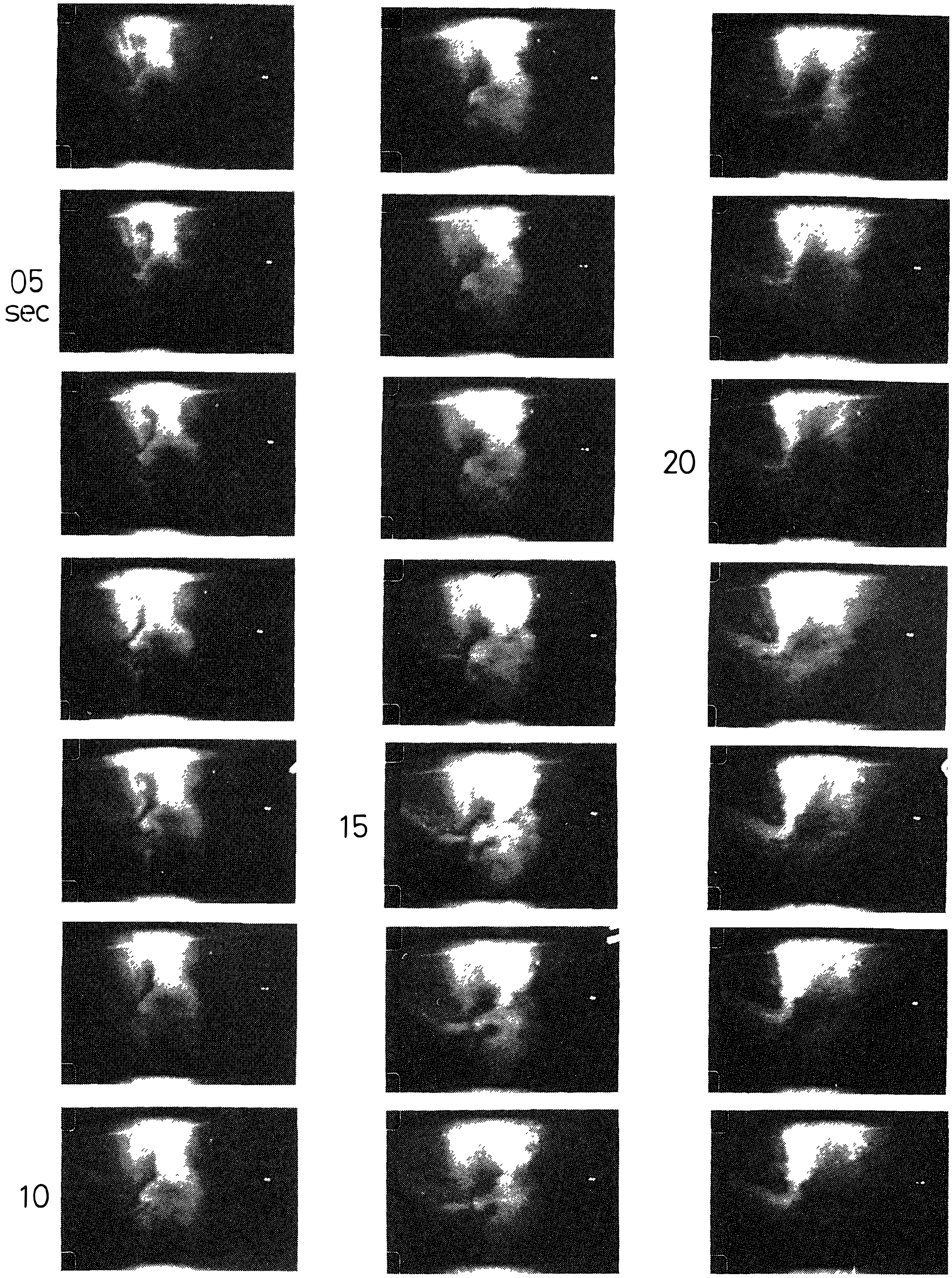


Fig. 5–2

↘*south and right is to the east. This appears at the low latitude border of the auroral activity after an auroral breakup.*

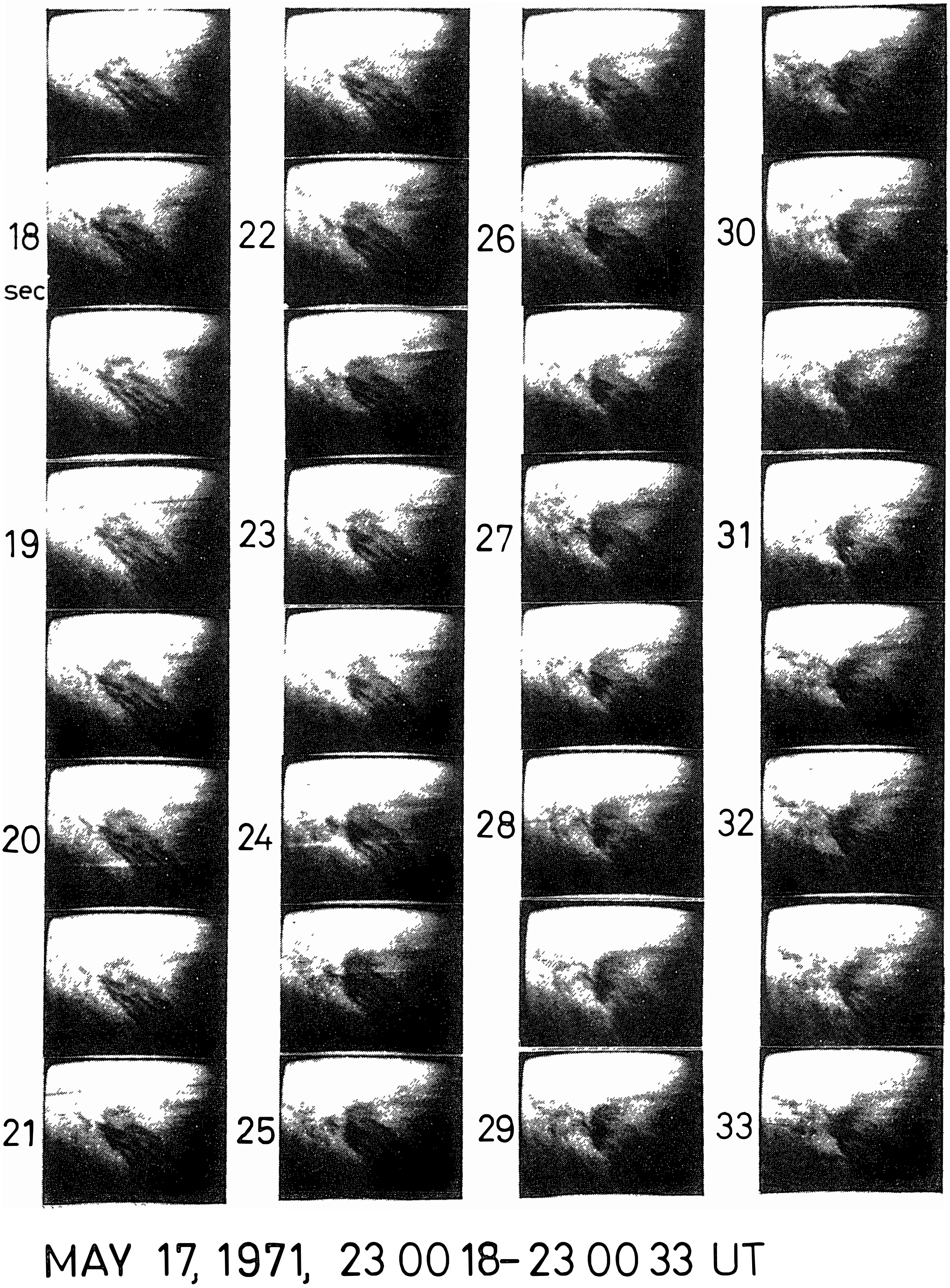
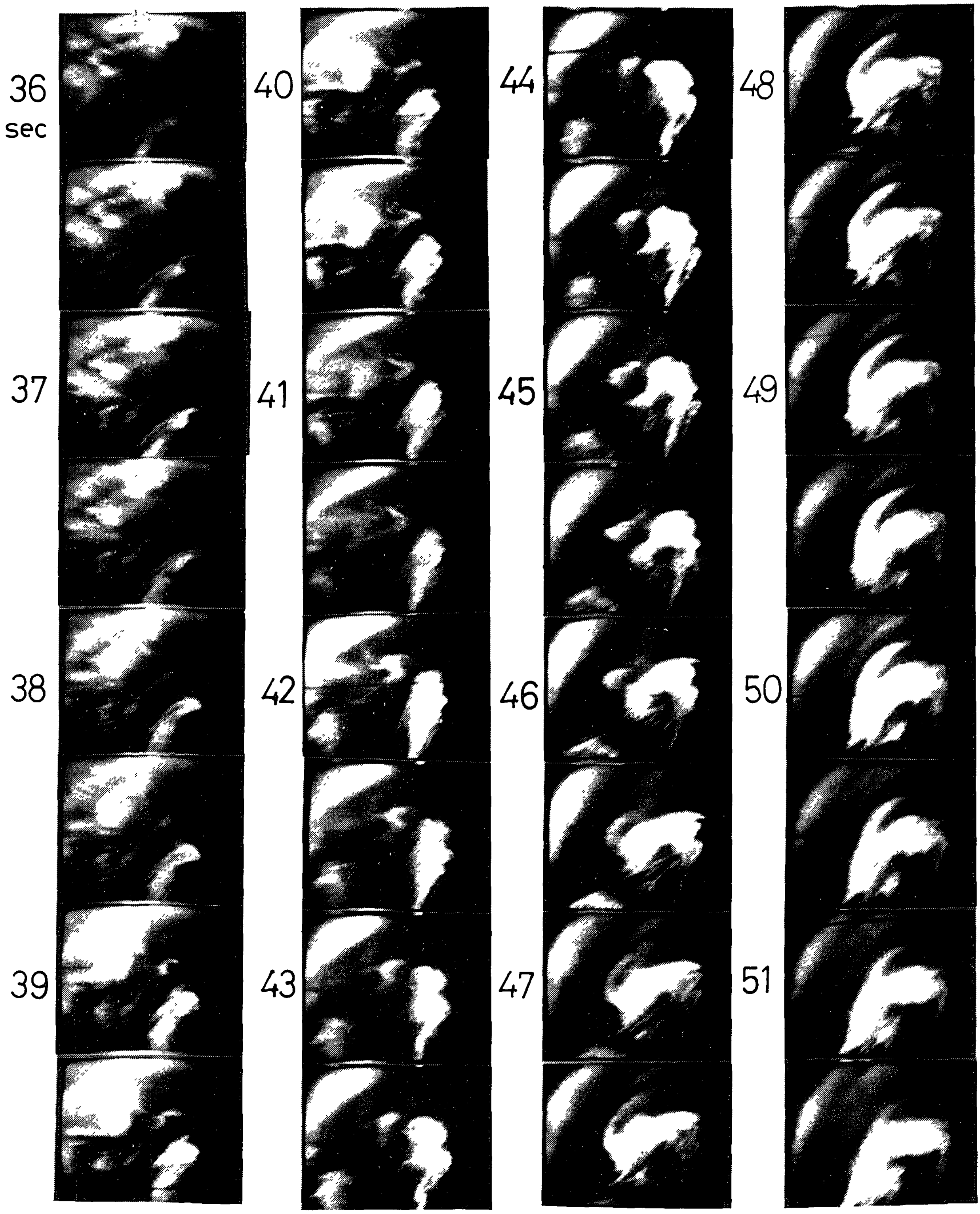


Fig. 6. A typical example of an auroral surface with dark holes. The number as well as the area of the dark holes gradually increases. It resembles a worm-eaten leaf, with veins left as auroral patches. The center of the frame is near the magnetic zenith. Top is to the magnetic south and right is to the magnetic east. This kind of aurora appears just after an auroral expansion. It seems to be a transient mode from sheet and smoke aurora to patches.



MAY 18, 1971, 23 56 36 - 23 56 51 UT

Fig. 9. An example of protrusive splitting and cusp like expansion through reshaping into a round loop. This may be regarded as a leading rotation. The viewing direction is magnetic N–W near zenith. Top is to the magnetic S–E and right is to the magnetic N–E. This is an active mode of splitting or rotational variations.

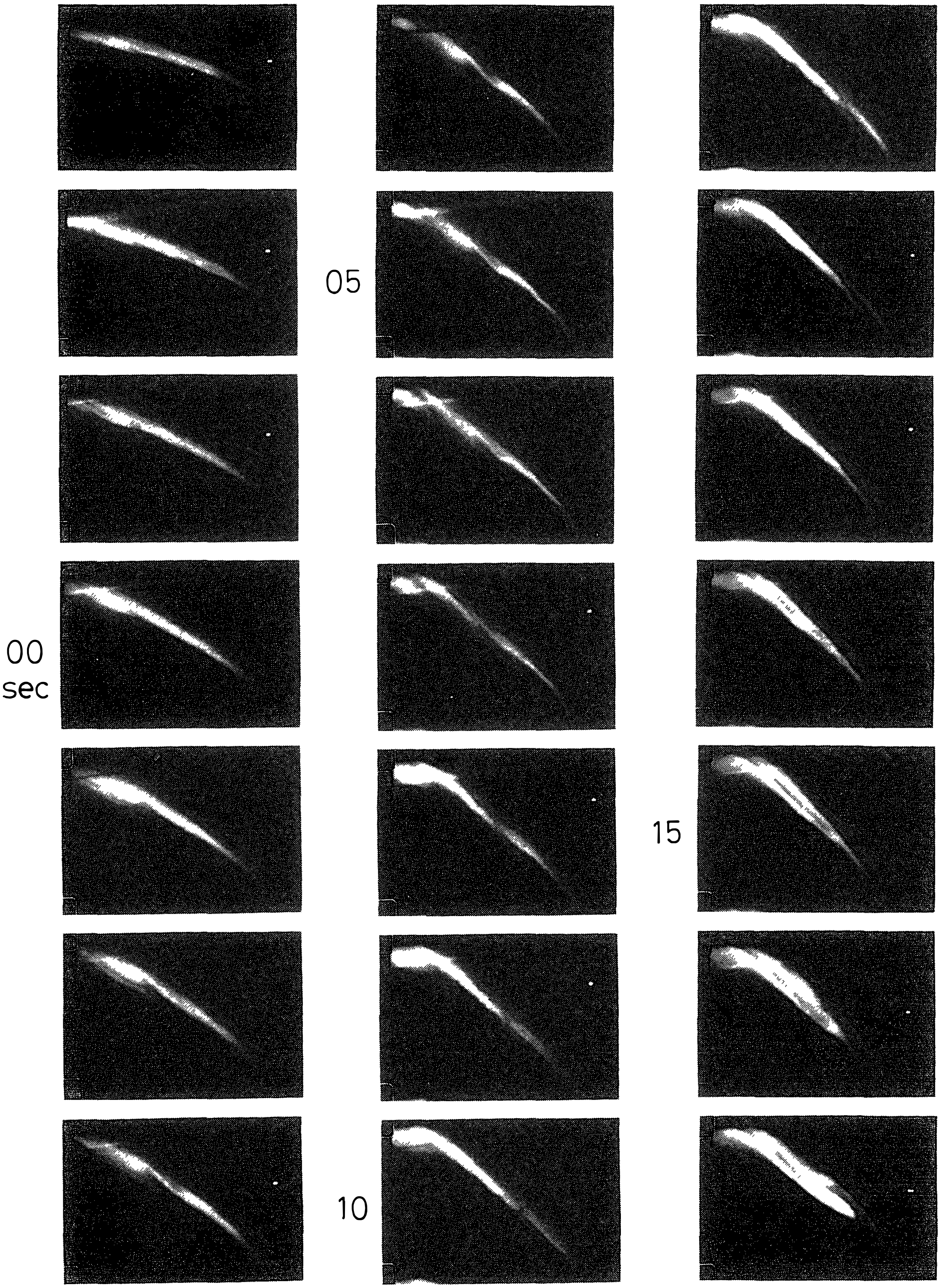


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Fig. 8-1

Fig. 8. Typical example of an arc splitting followed by a rotational unfolding. During the course of the↗

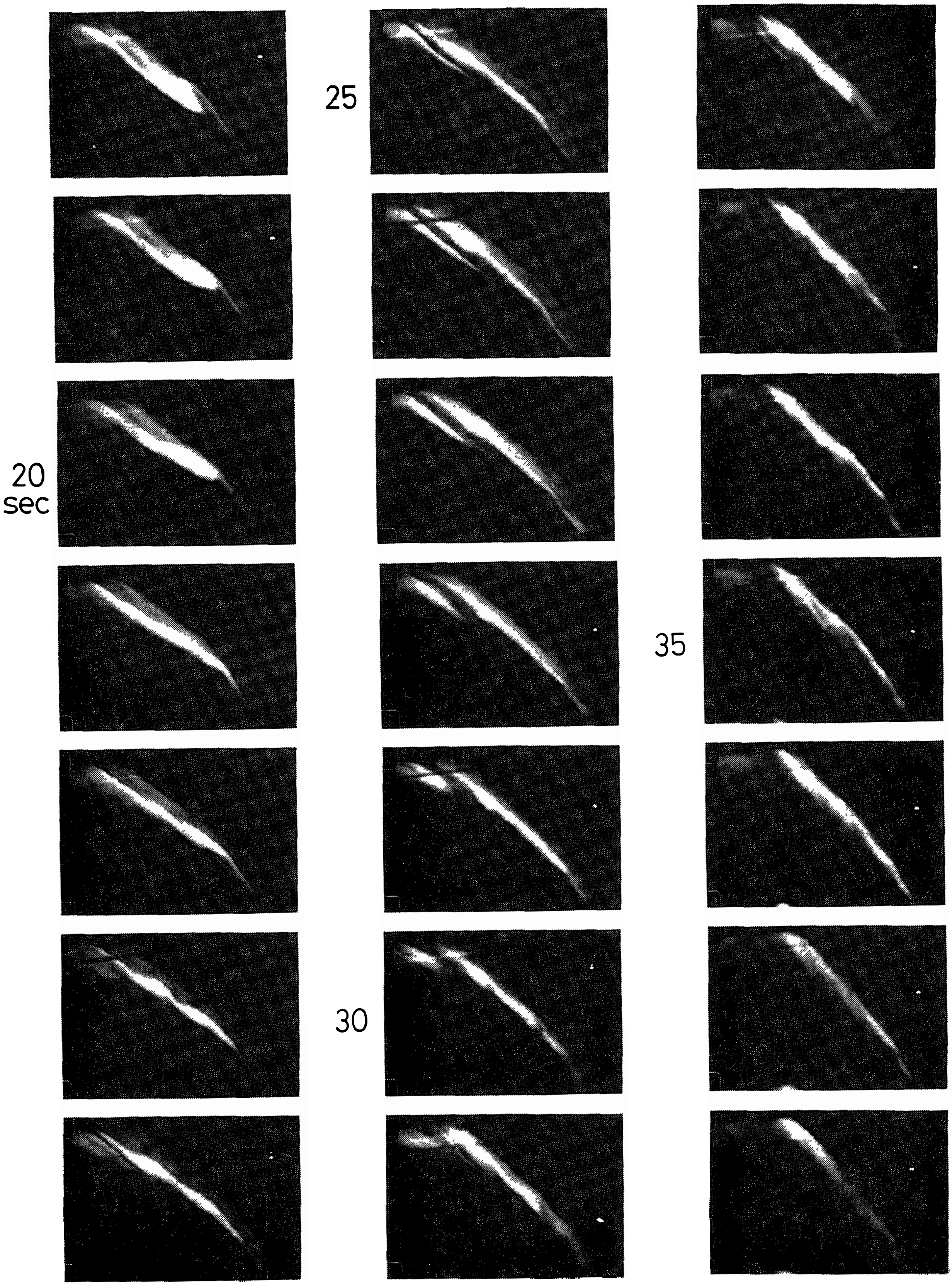
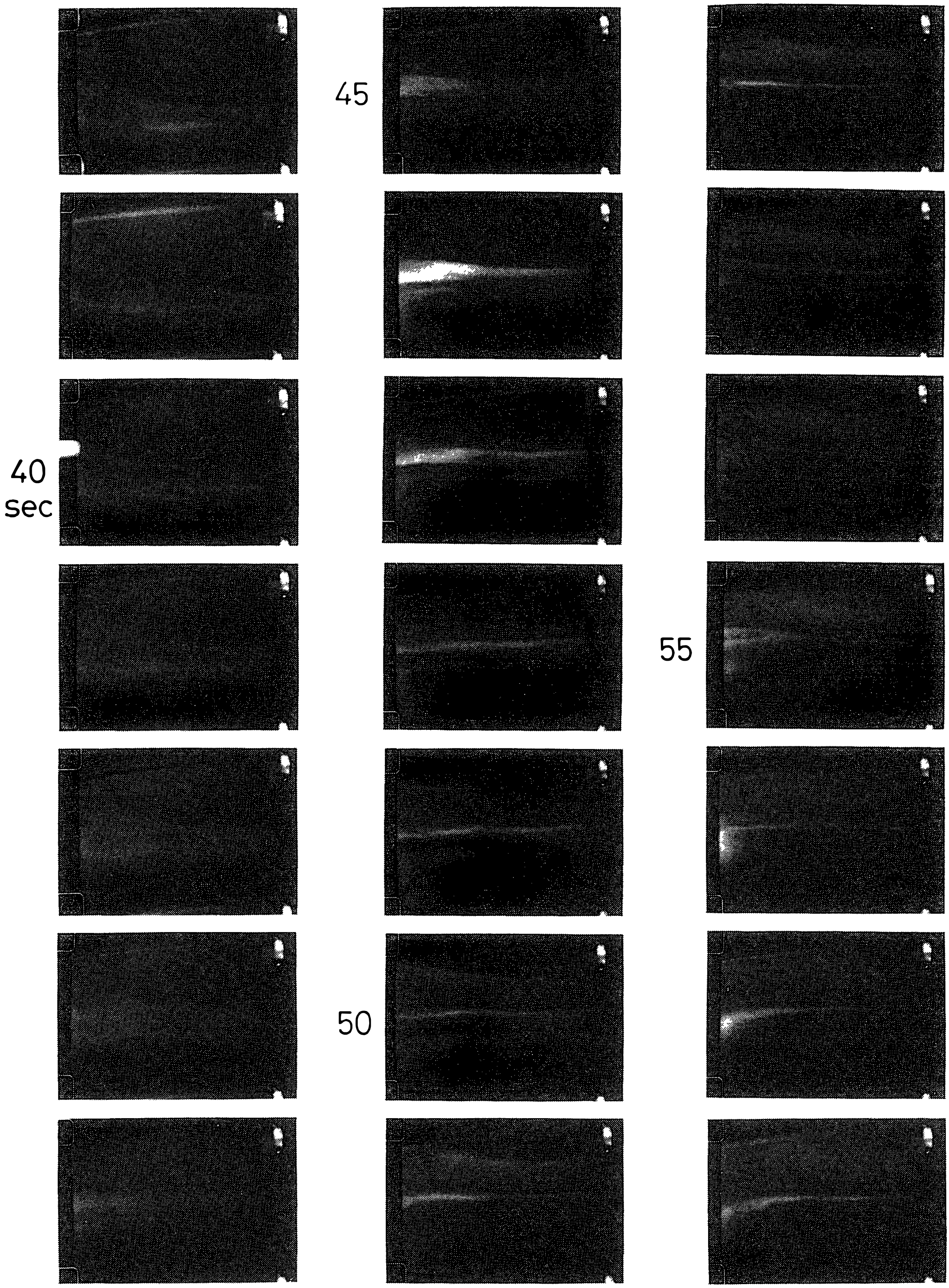


Fig. 8–2

↘*unfolding, a typical S-structure of arc is seen at 034018. This resembles stretching out of a piece of paper previously folded. The direction is nearly to the magnetic zenith. The top is to the magnetic south, and right is to the magnetic east.*



MAY 17 1971 22 43 38–22 43 58 UT

Fig. 10. *An example of splitting through lateral drift of a striation aurora. This is often seen in the smoke auroral region after an auroral expansion. The direction is approximately to the magnetic zenith. The top is to the magnetic south, and right is to the magnetic east.*

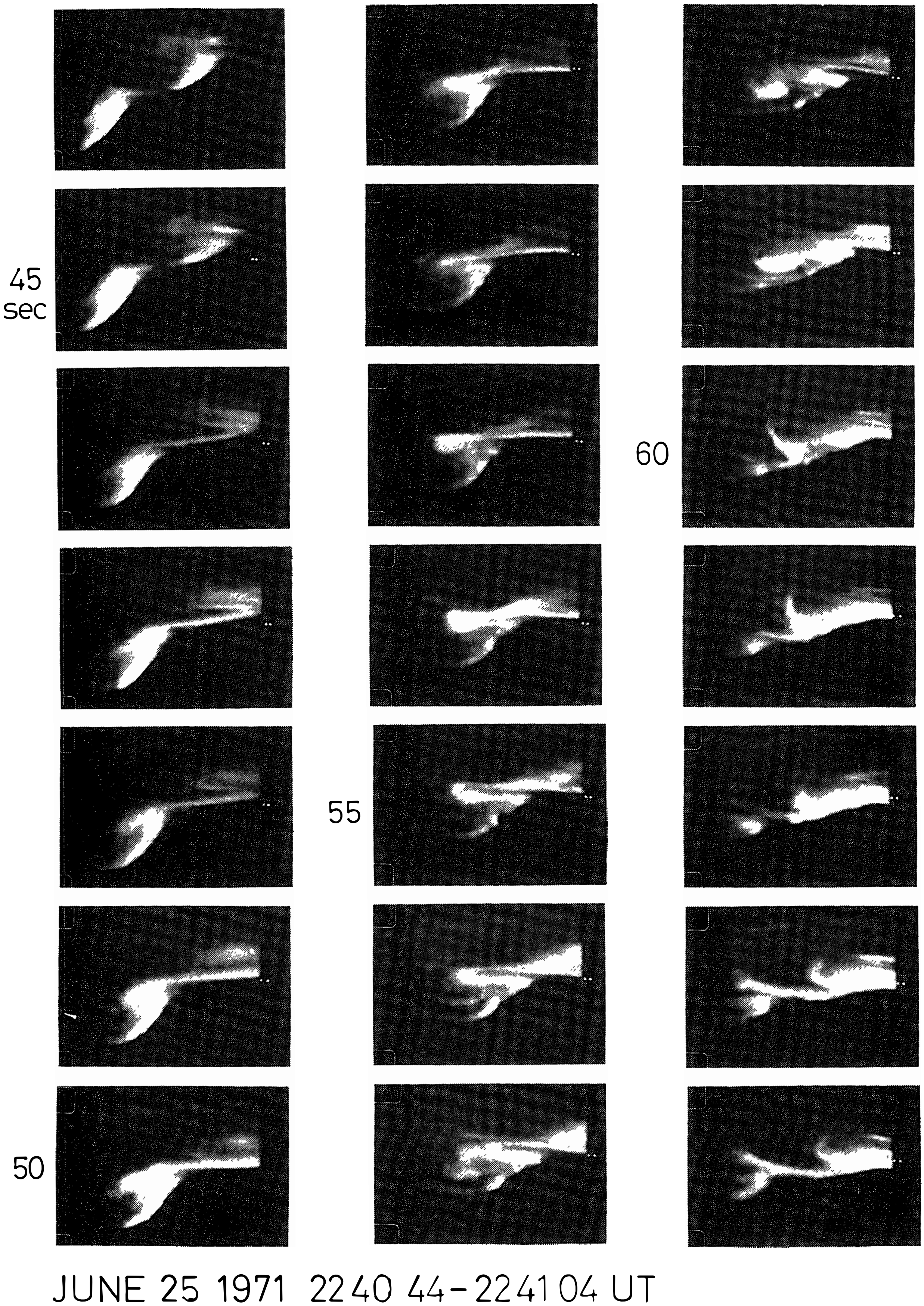


Fig. 11. An example of multiple folding-over of a sheet aurora. It finally tends to be a flame-like structure. The center of the frame is near the magnetic zenith. Top is to the magnetic south and right is to the magnetic east.

Fig. 12-1

Fig. 12. An example of a splitting-fold over-reconnection. The split sheet begins to fold over at 29.7 sec,

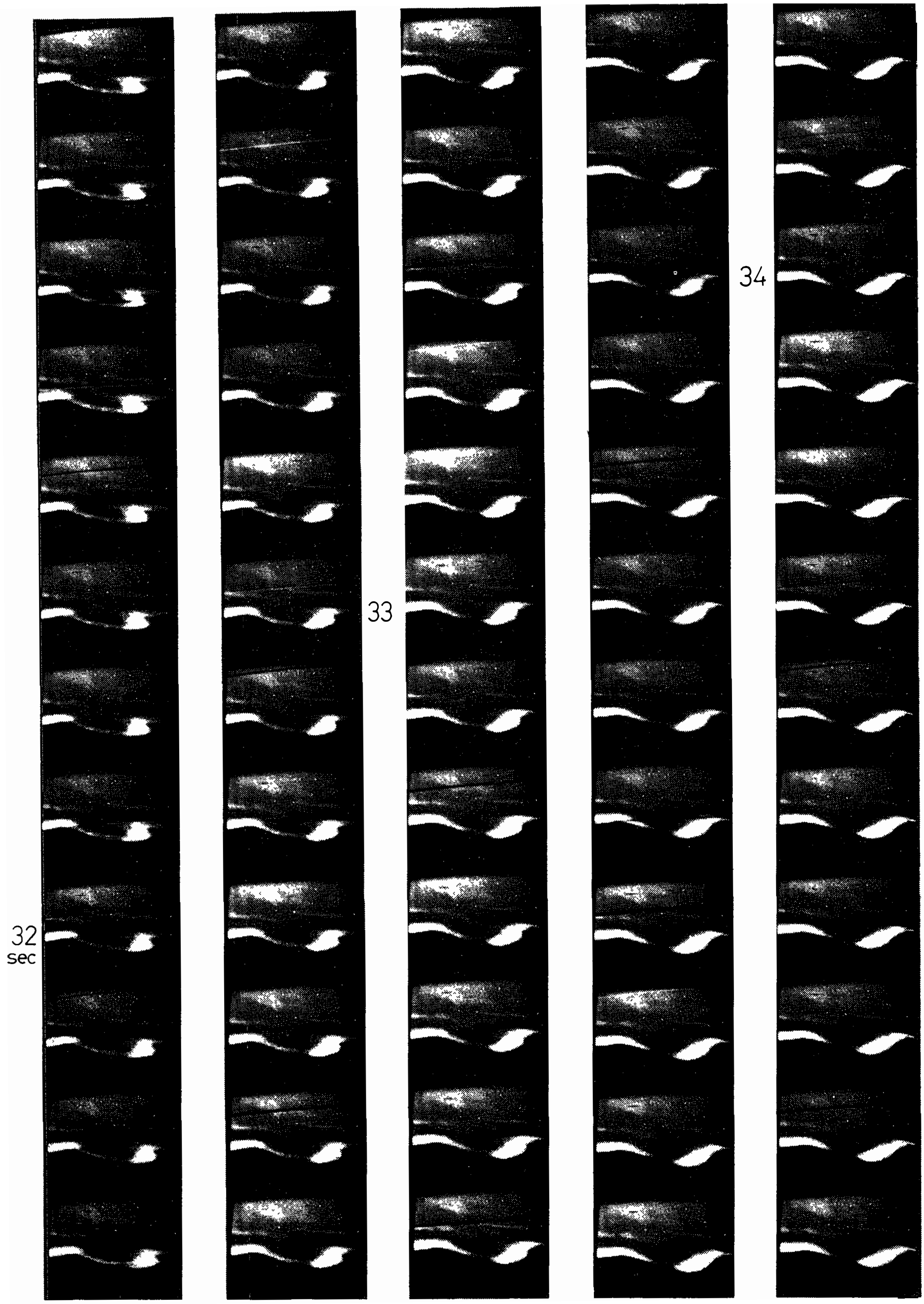


Fig. 12–2

↘*then it reconnects to another branch from the left at 30.1 sec with disruption of the primary arc at 30.9 sec. Magnetic north near horizon. Top is to the magnetic south and right is to the magnetic east.*

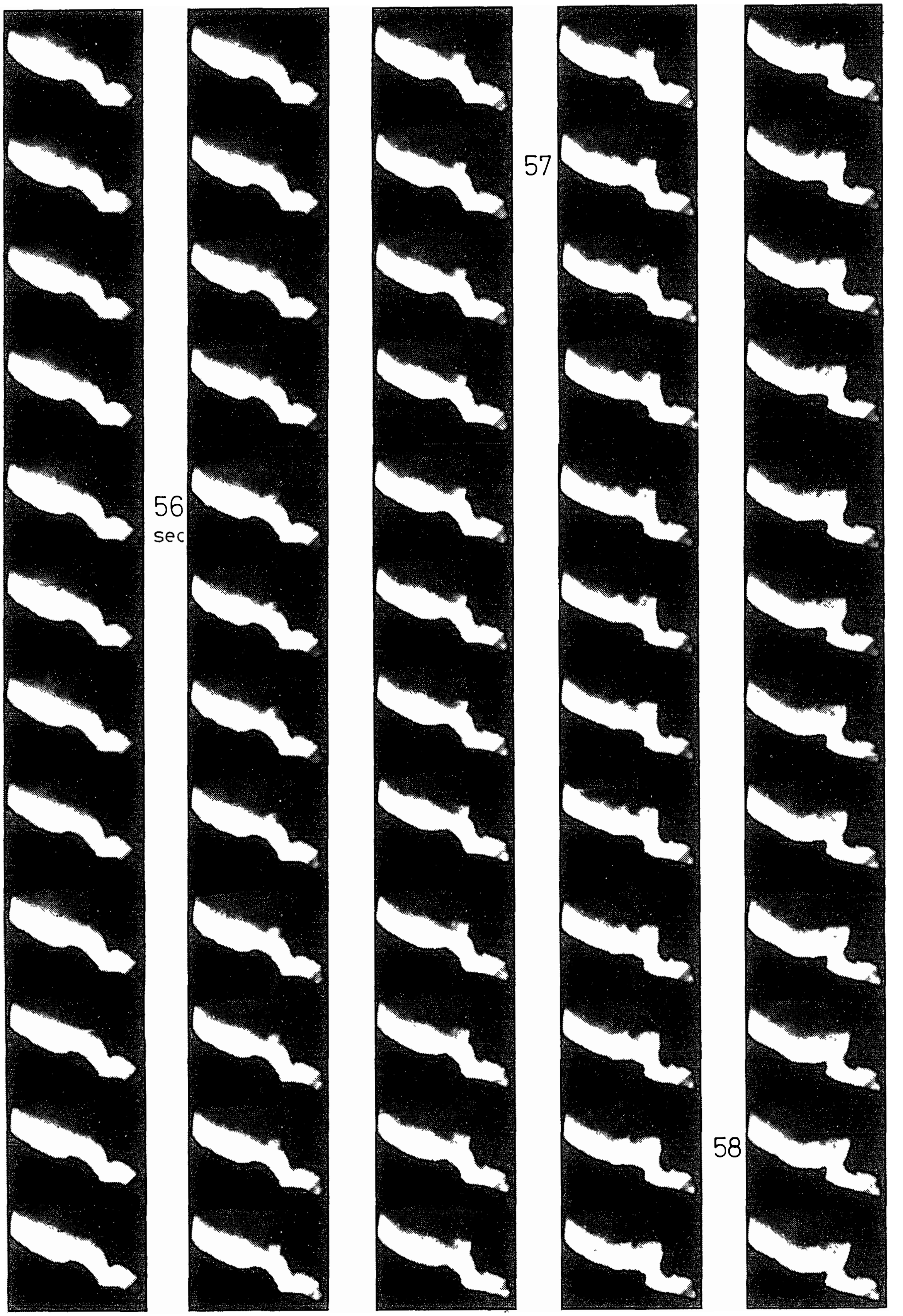


Fig. 13-1

Fig. 13. An example of sheet-detachment leading to a detachment-fading. A small sheet fragment begins↗

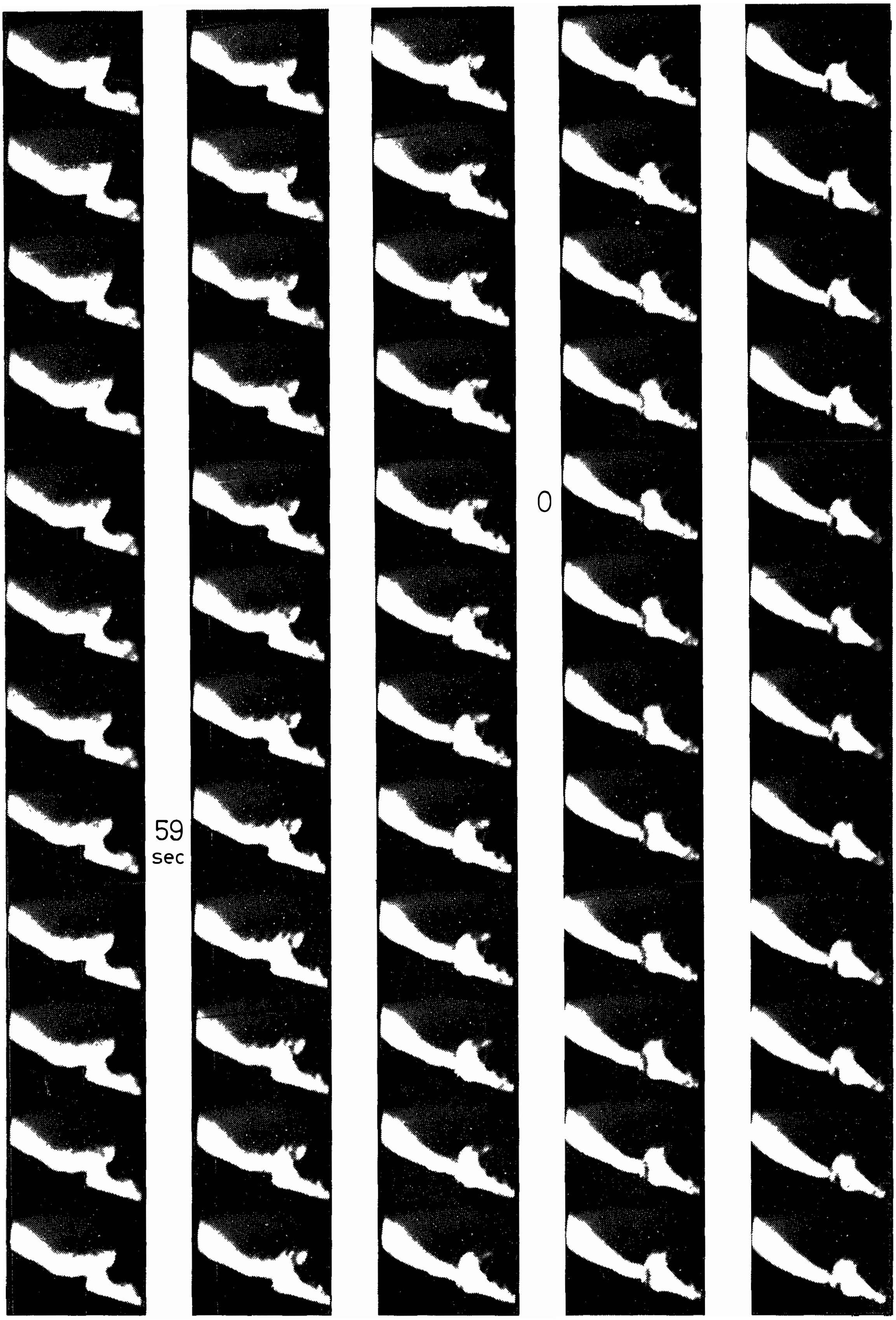
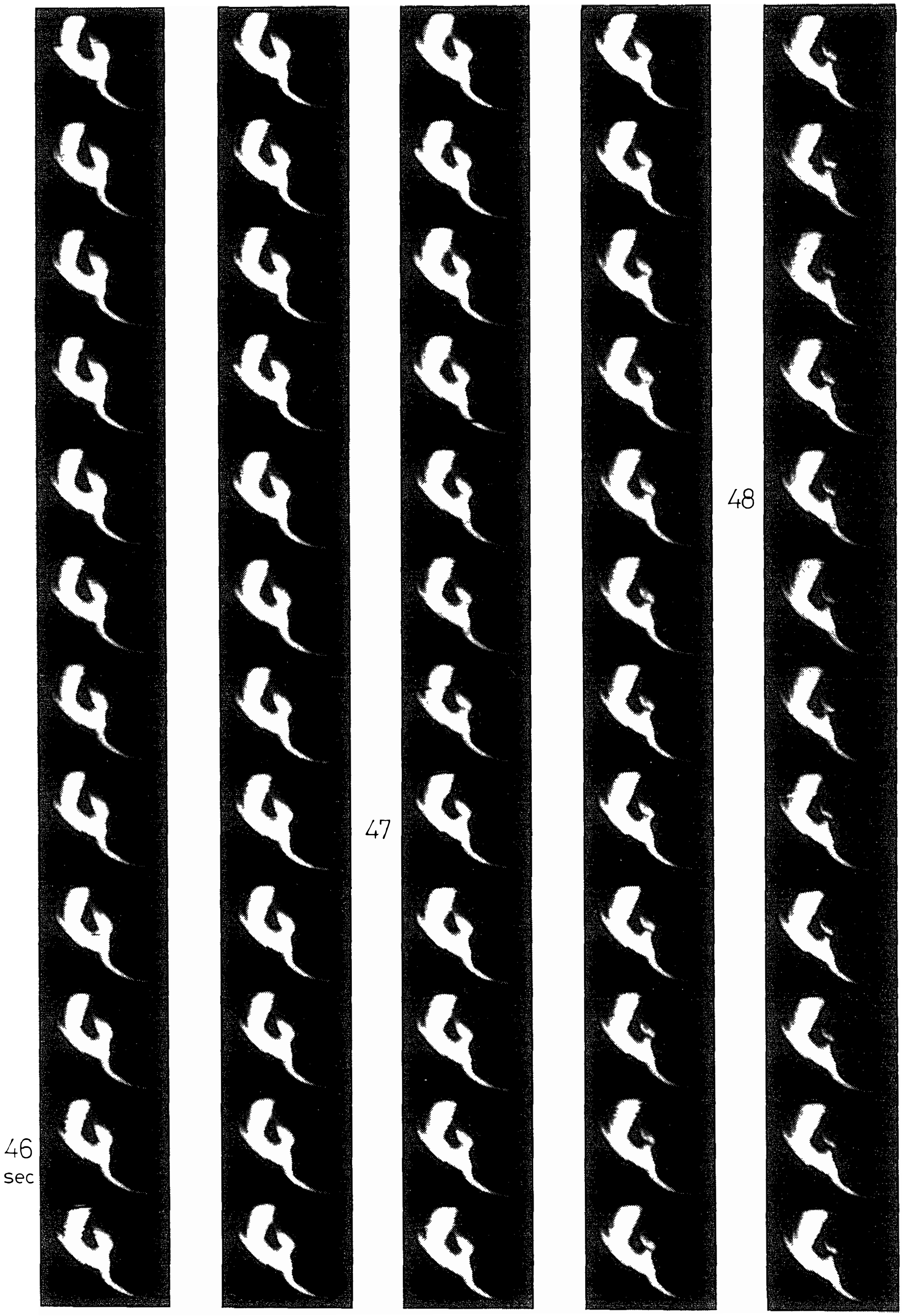


Fig. 13–2

↘*to split and fold over at 55.8 sec, and it detaches from the main arc at 58.7 sec, then fades out. Magnetic south-west. Top is to the magnetic N–E and right is to the magnetic N–W.*



SEPT. 25, 1971, 22 18 46 – 22 18 51 UT

Fig. 14–1

Fig. 14. An example of loop-detachment leading to a detachment-fading. A small loop, born from the main↗

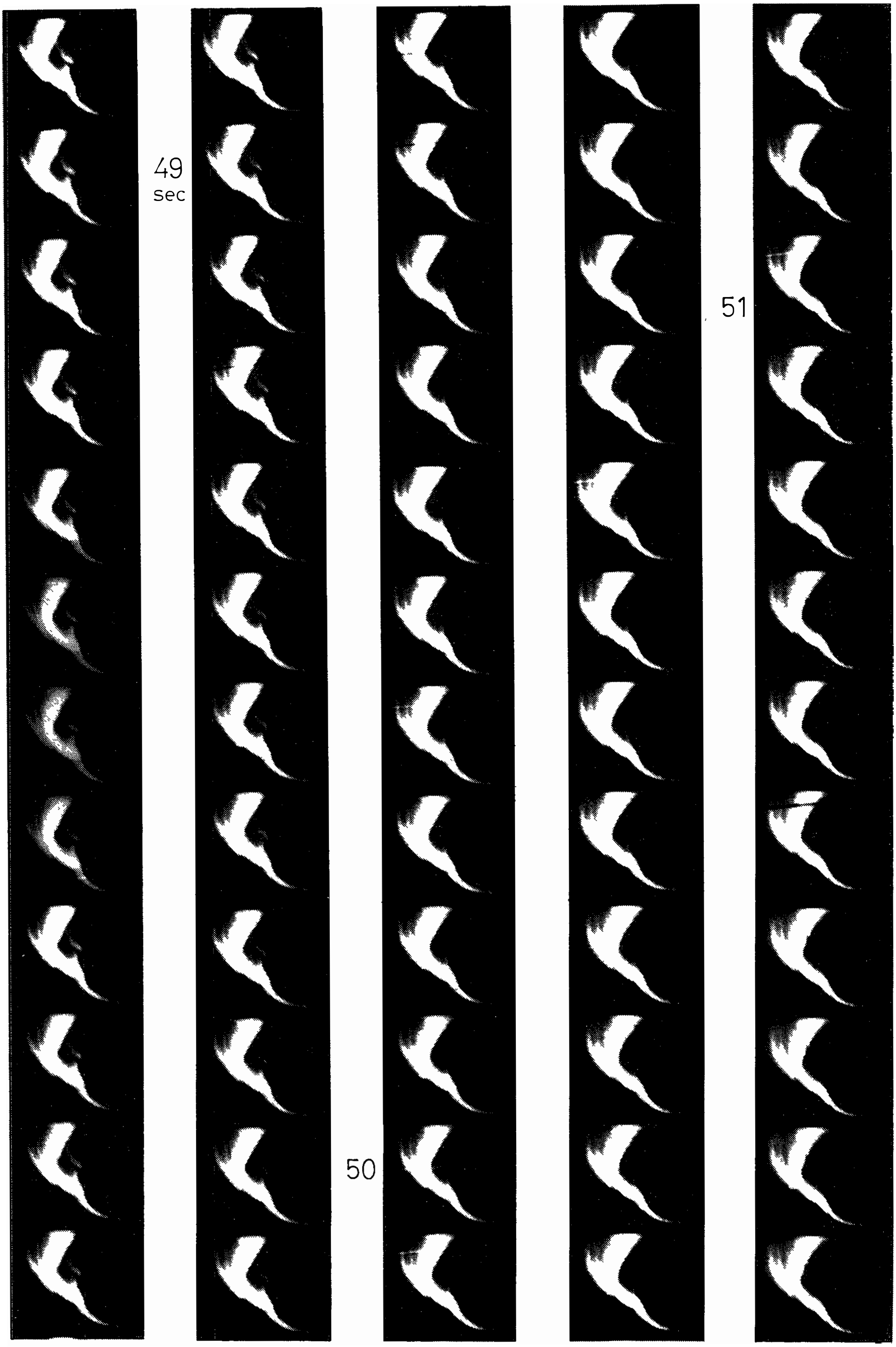


Fig. 14–2

↘arc through a splitting, detaches at 47.0 sec from the main arc and fades at 49.9 sec. Magnetic N–E, near horizon. The top is to the magnetic S–W, and right is to the magnetic S–E.

Fig. 15–1

Fig. 15. The split arc, after fold-over, reconnects to the right-hand side arc at 18.7 sec, then the primary arc begins to disrupt at 18.8 sec. The disruption is completed at 19.2 sec. During the course, many↗

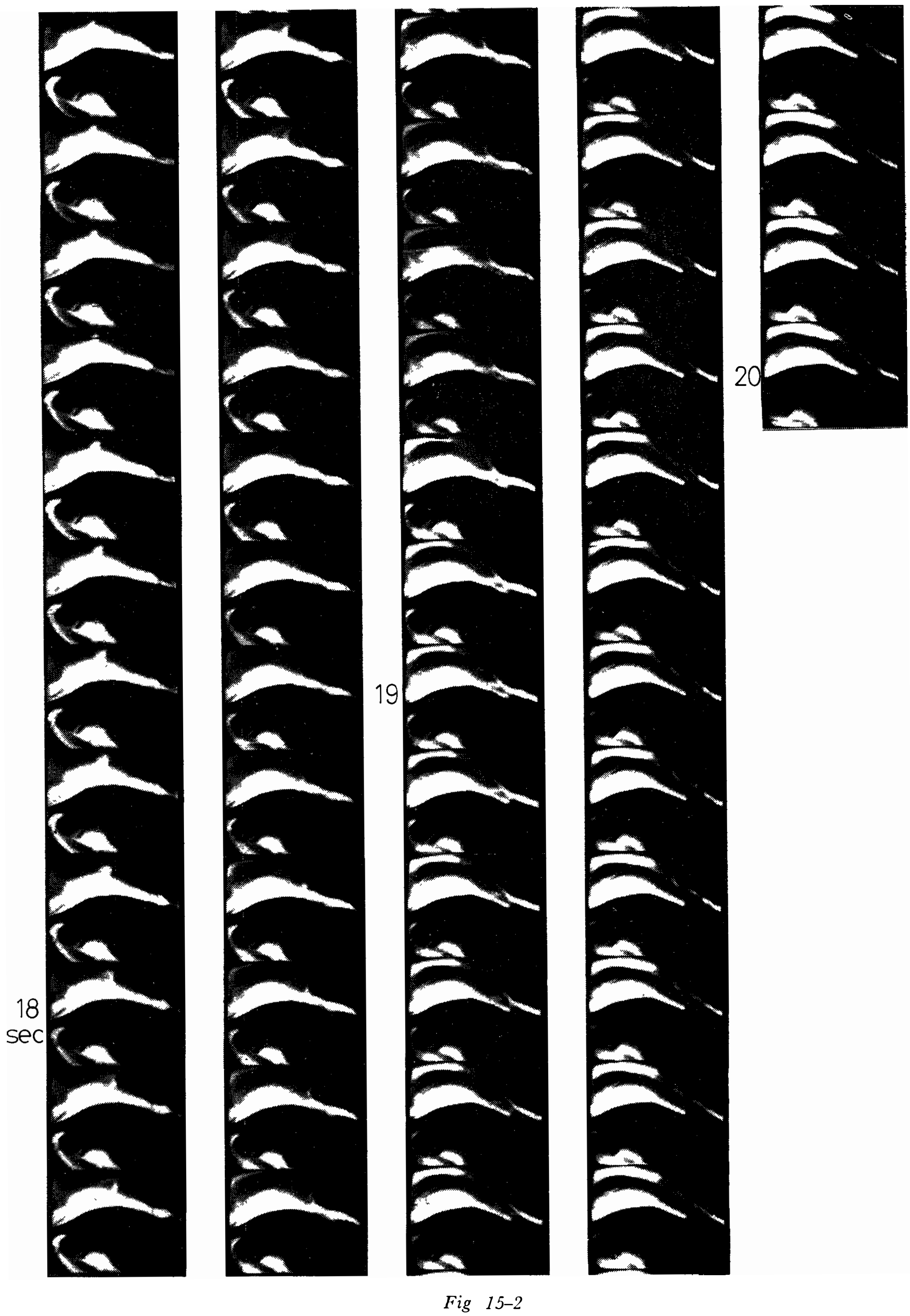


Fig 15–2

↘*fold-over structures (small Ω-bands) rapidly propagate to the right along the arc for example, from 17.5 sec to 18.2 sec. Both of these deformations are seen at and near the surge and poleward front during an active phase of an auroral expansion. Magnetic west near zenith. The top is to the magnetic east and right is to the magnetic north.*

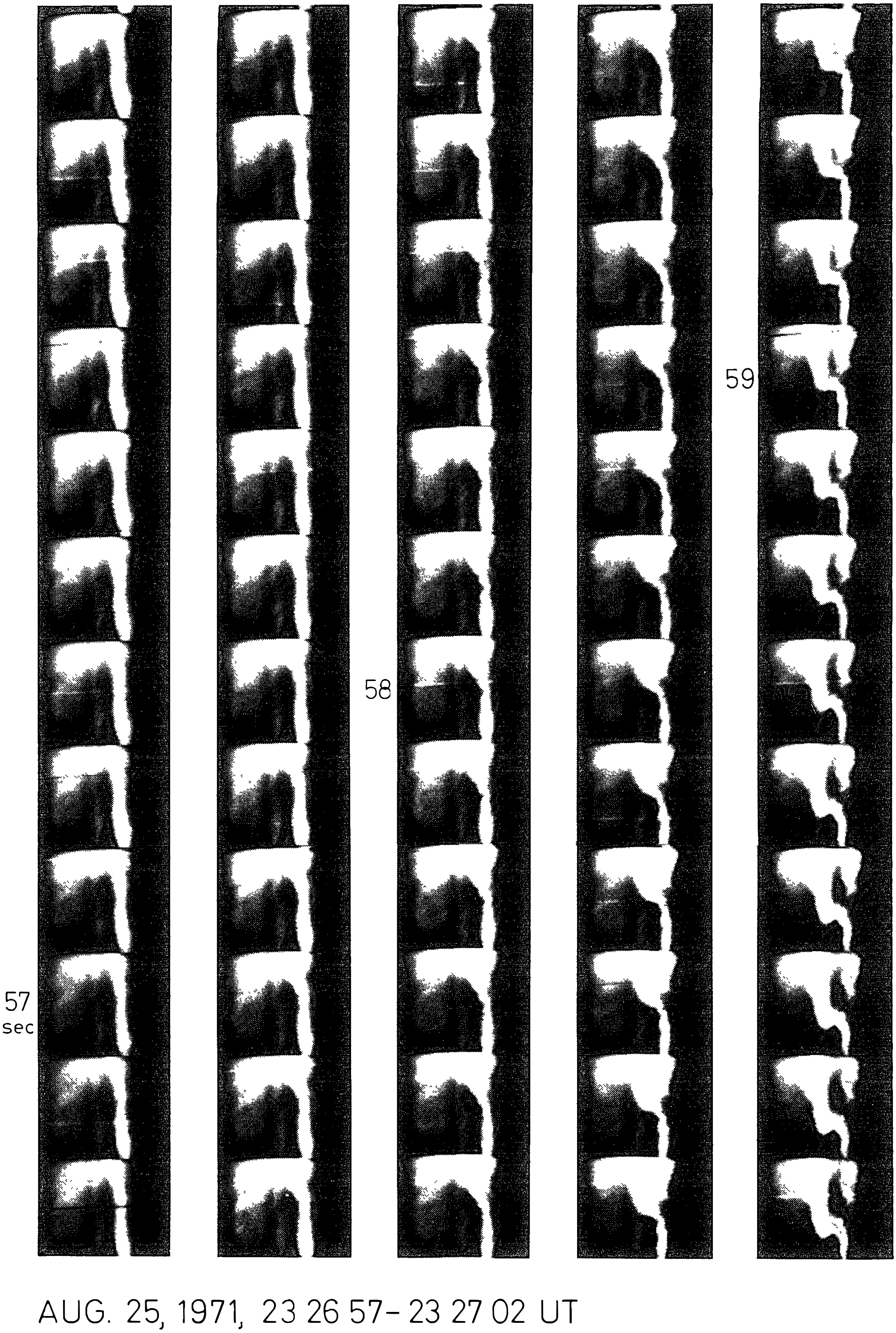


Fig. 16-1

Fig. 16. An example of fluttering Fluttering consists of small scale Caterpiller tread-like expansions or a↗

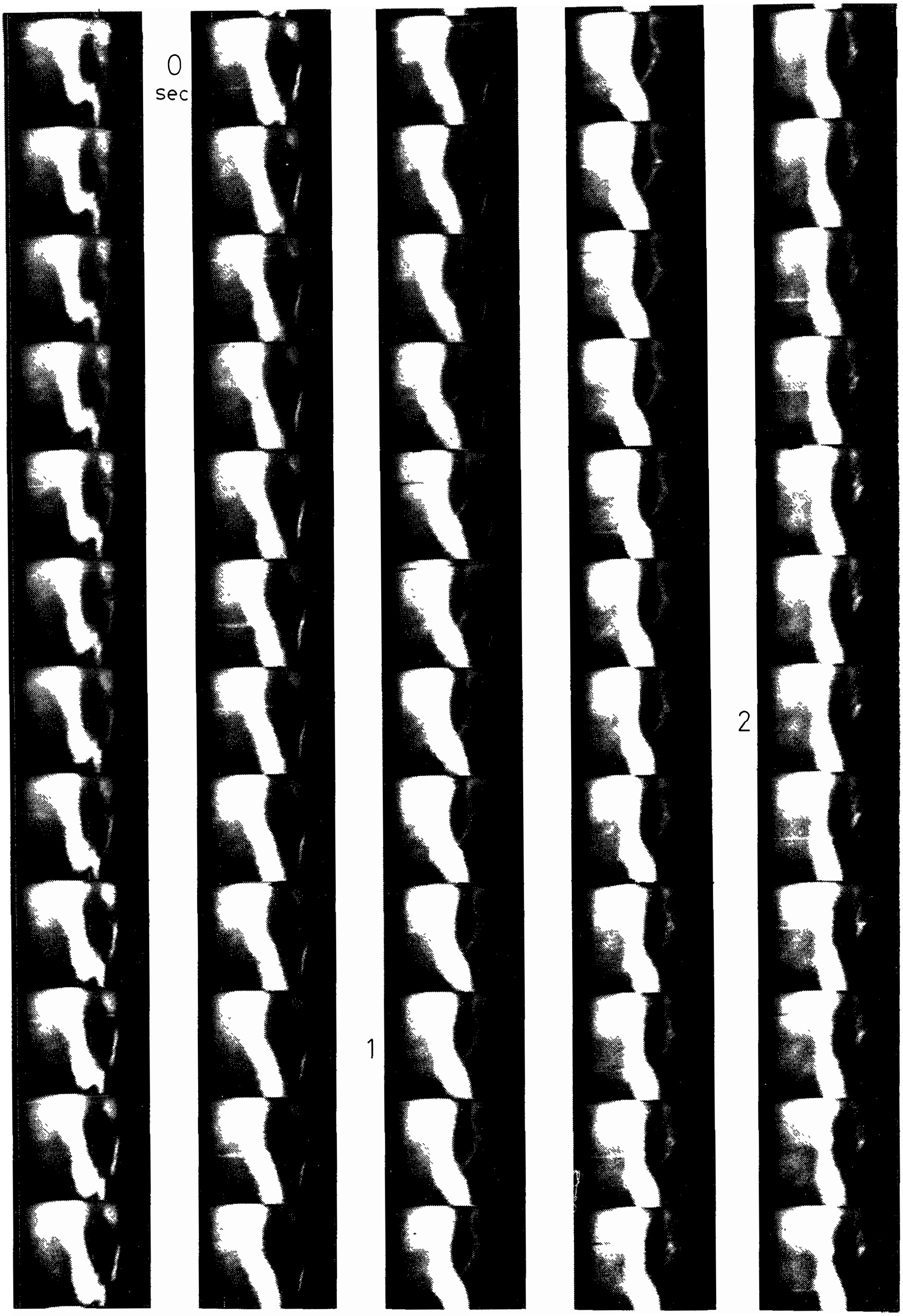


Fig. 16–2

↘propagation of an S-structure along an arc. Direction is magnetic west near zenith. The top is to the magnetic east, and right is to the magnetic north. The propagation direction of fluttering structure here is westward along arcs.

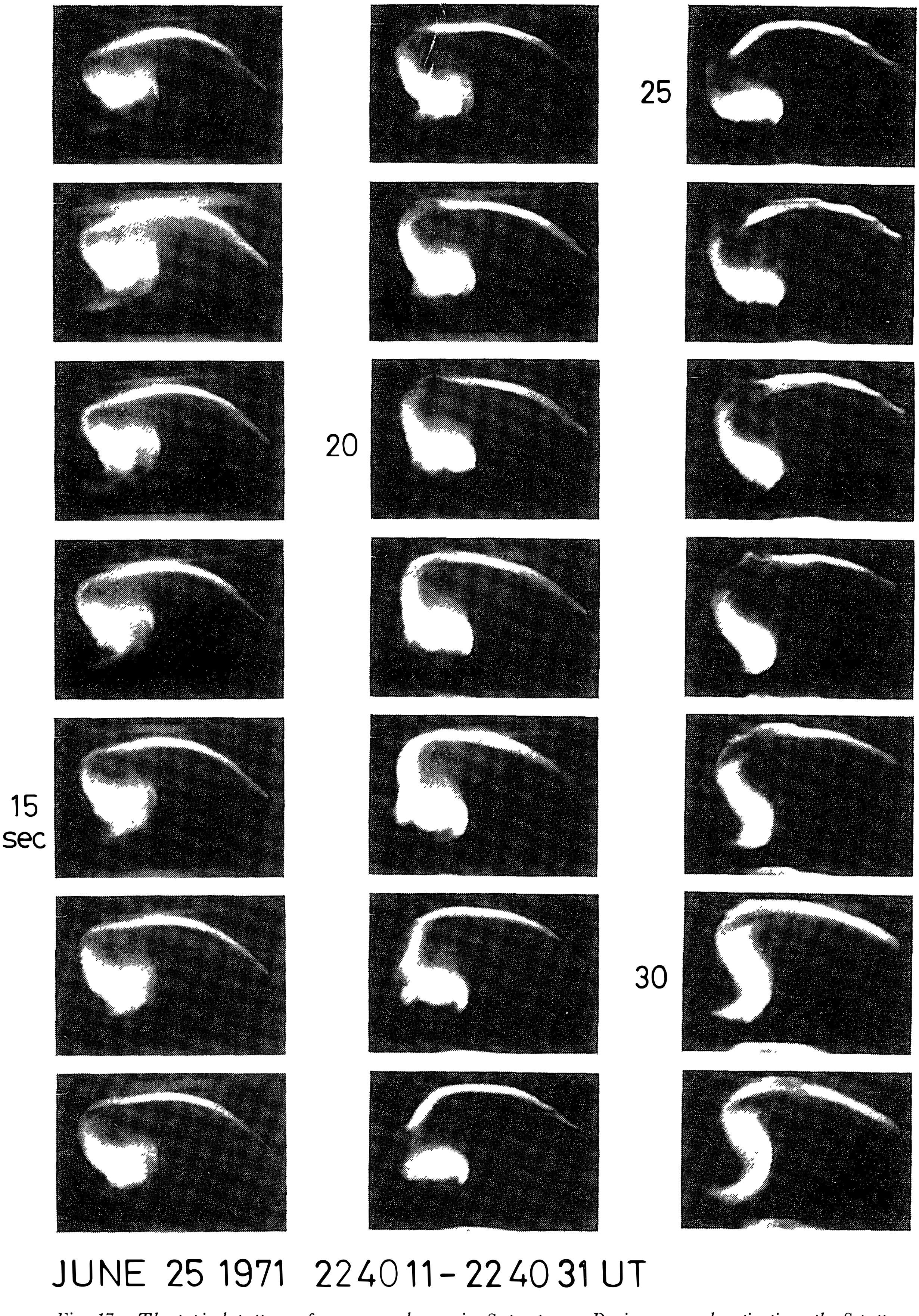


Fig. 17. The typical pattern of an auroral arc is S-structure. During auroral activation, the S-pattern repeatedly appears along an arc. Splitting and folding-over deforms a primary S-pattern, making it complex, but the arc finally tends to become the similar S-pattern, more extended than the primary. A shear-like folding of an arc is seen at 224026, near the top of the frame. The center of the frame is approximately coincident to the magnetic zenith. Top is to the magnetic south, and right is to the magnetic east.

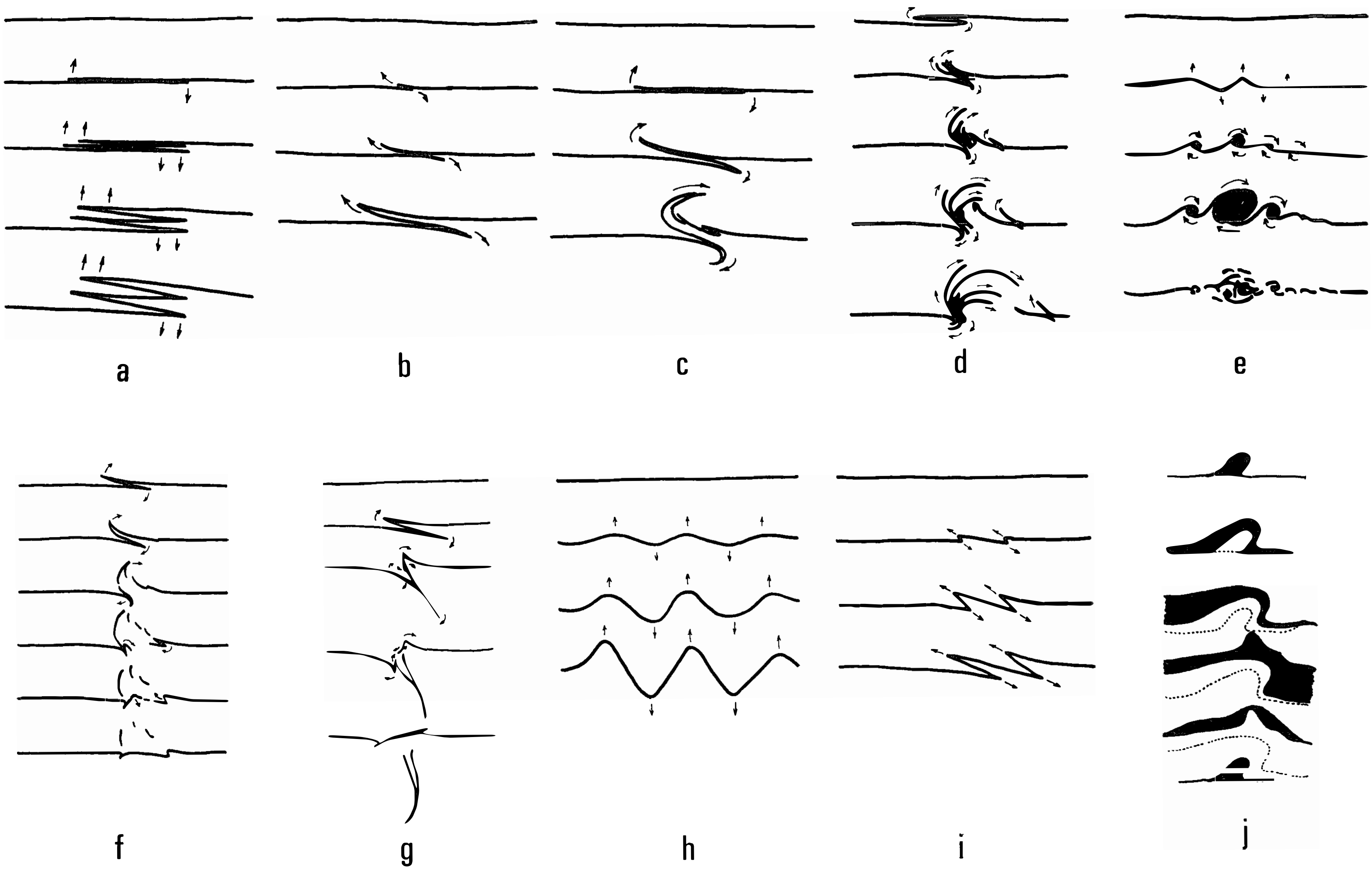


Fig. 18. Schematic illustrations of elementary deformations. a) simple splitting, b) protrusive splitting, c) folding over, d) leading rotation, e) trailing rotation, f) sheet to sheet deformation (disruption and reconnection), g) sheet detachment, h) simple meandering, i) shear folding, j) quasi-periodic sequential switching.

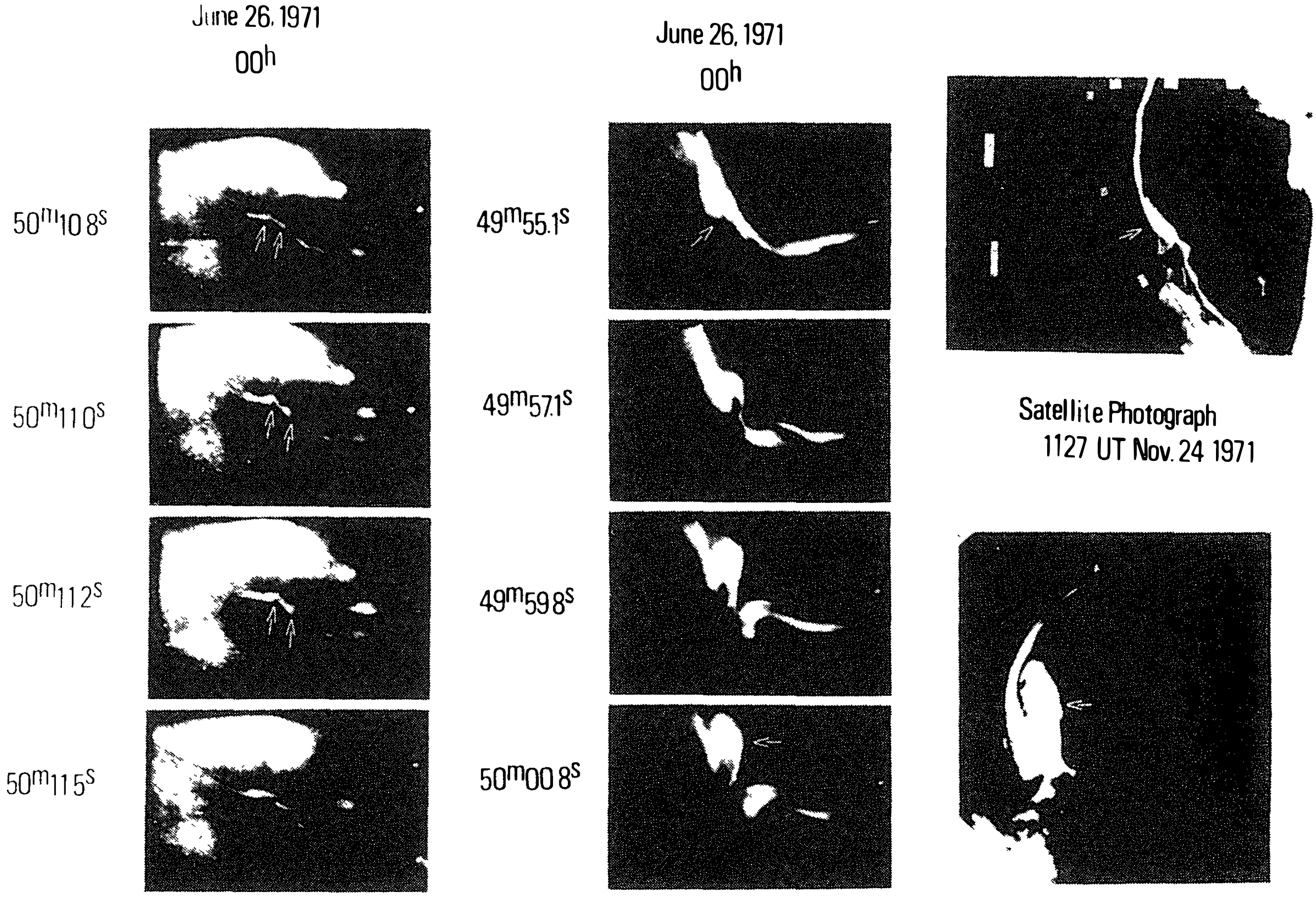
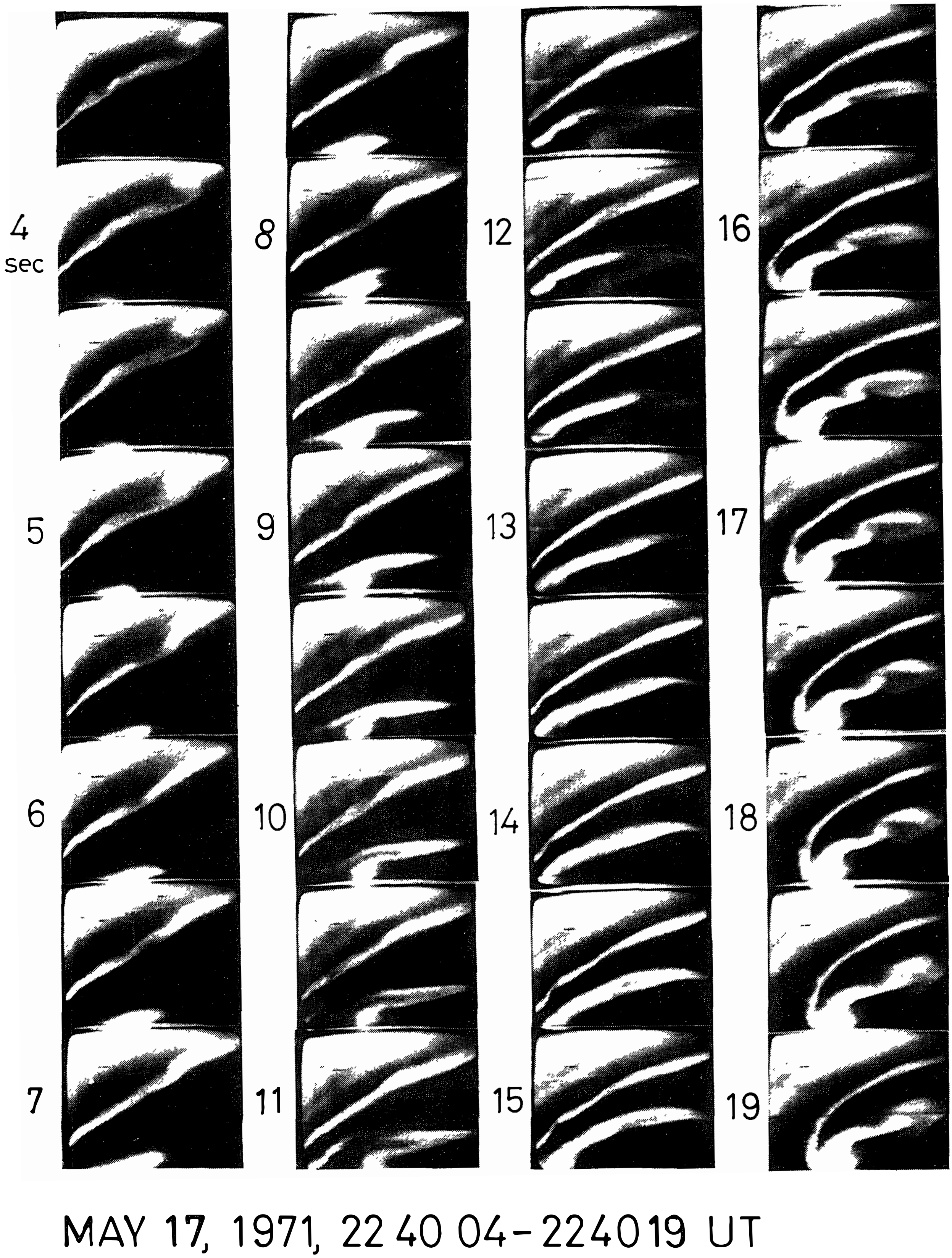


Fig. 19. Characteristic S-pattern of discrete aurora of various sizes. The scales of S in the left, the middle and the right column are about 3 km, 30 km and 1000 km, respectively. The formation times of these S-patterns are about 0.4 sec, 5 sec and few minutes, respectively, so that the deformation speed is approximately constant being several km/sec. The right column is a reproduction from DAPP photographs.



MAY 17, 1971, 22 40 04 - 22 40 19 UT

Fig. 21. Typical example of a cusp-like expansion of arc. This type of deformation of large scale is often seen at the front of westward travelling surges during an expansion. The center of the frame is nearly the magnetic zenith. The top is to the magnetic south, and right is to the magnetic east.

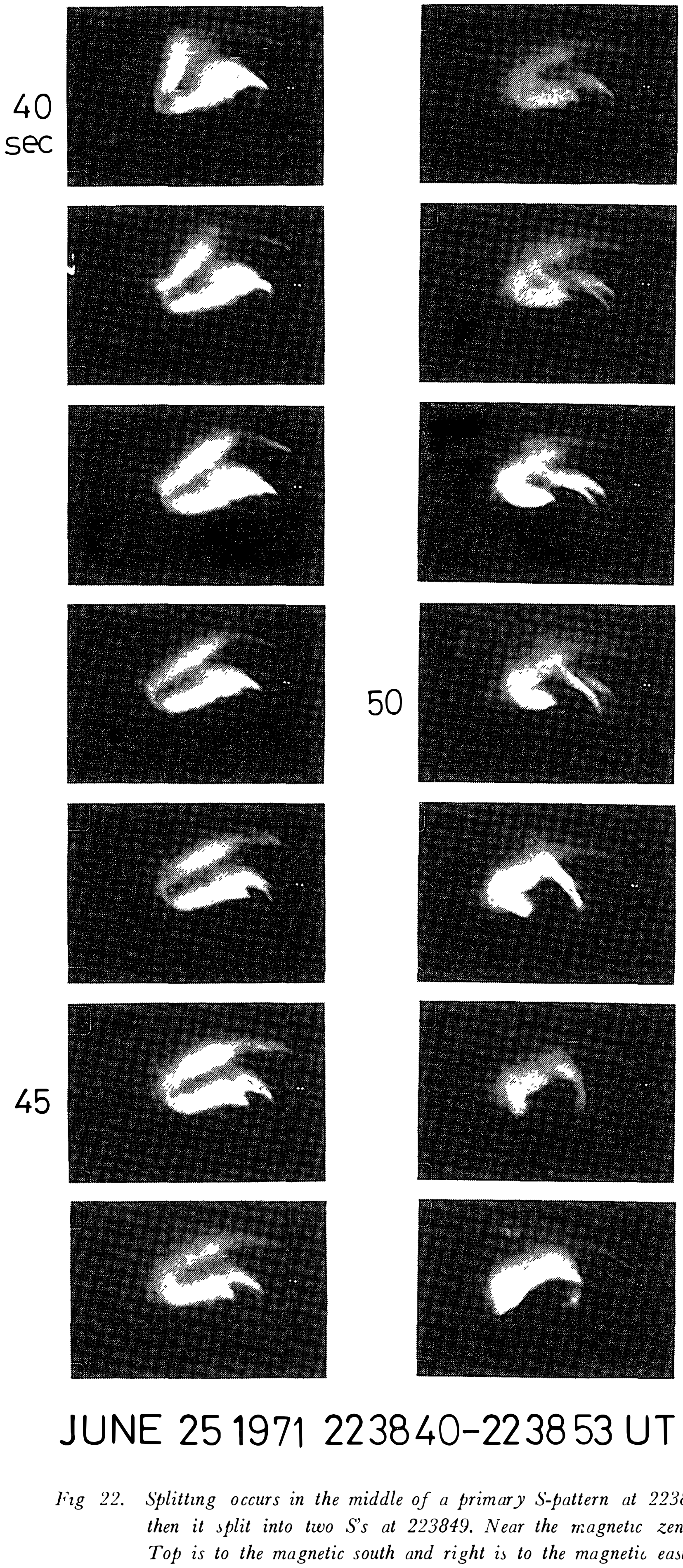


Fig 22. Splitting occurs in the middle of a primary S-pattern at 223843 then it split into two S's at 223849. Near the magnetic zenith. Top is to the magnetic south and right is to the magnetic east.

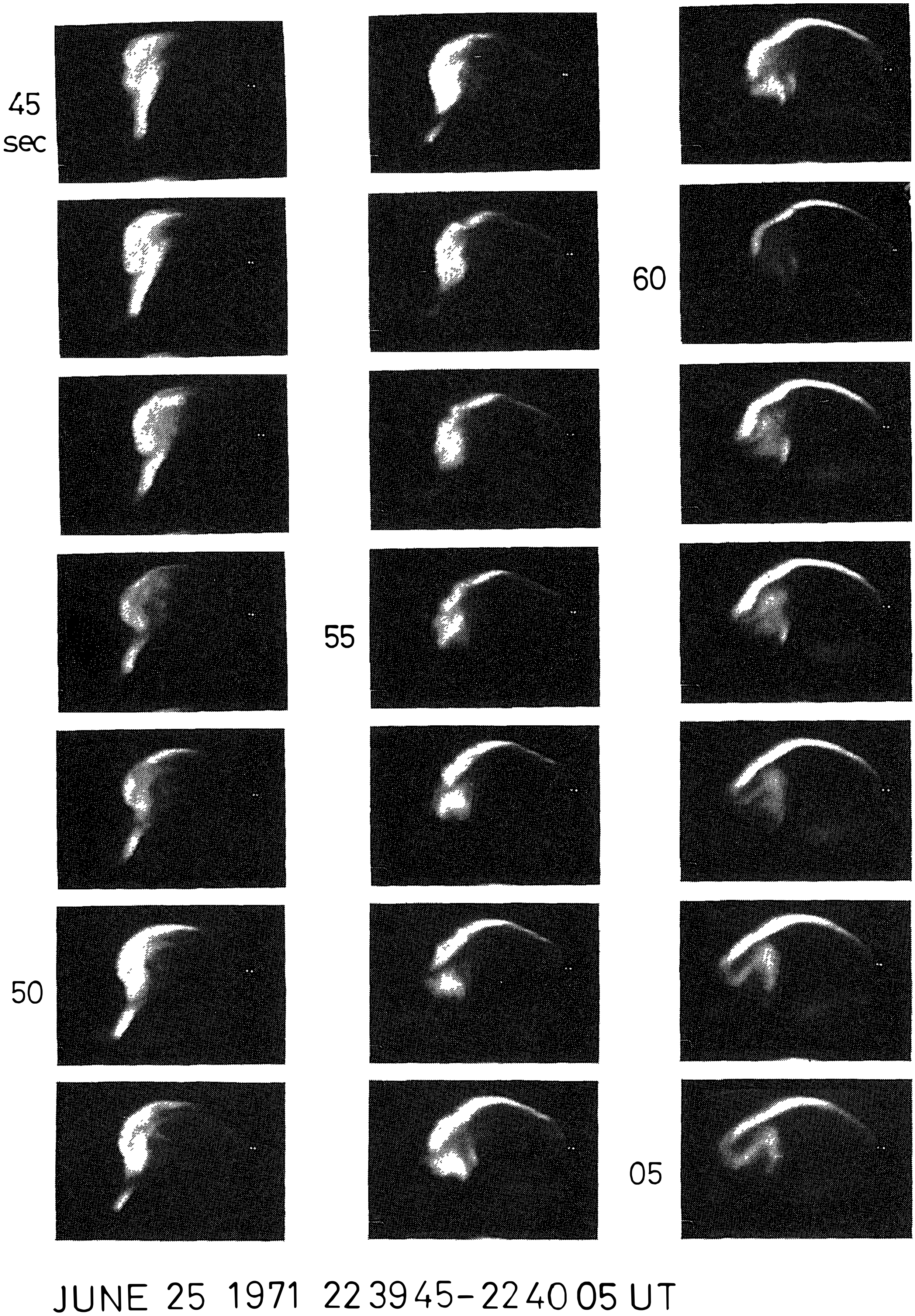


Fig. 23. A primary S-pattern splits in the middle and the split parts clockwisely unfold reshaping into an apparent counterclockwise spiral at 224004. The center is approximately coincident to the magnetic zenith. Top is to the magnetic south and right is to the magnetic east.

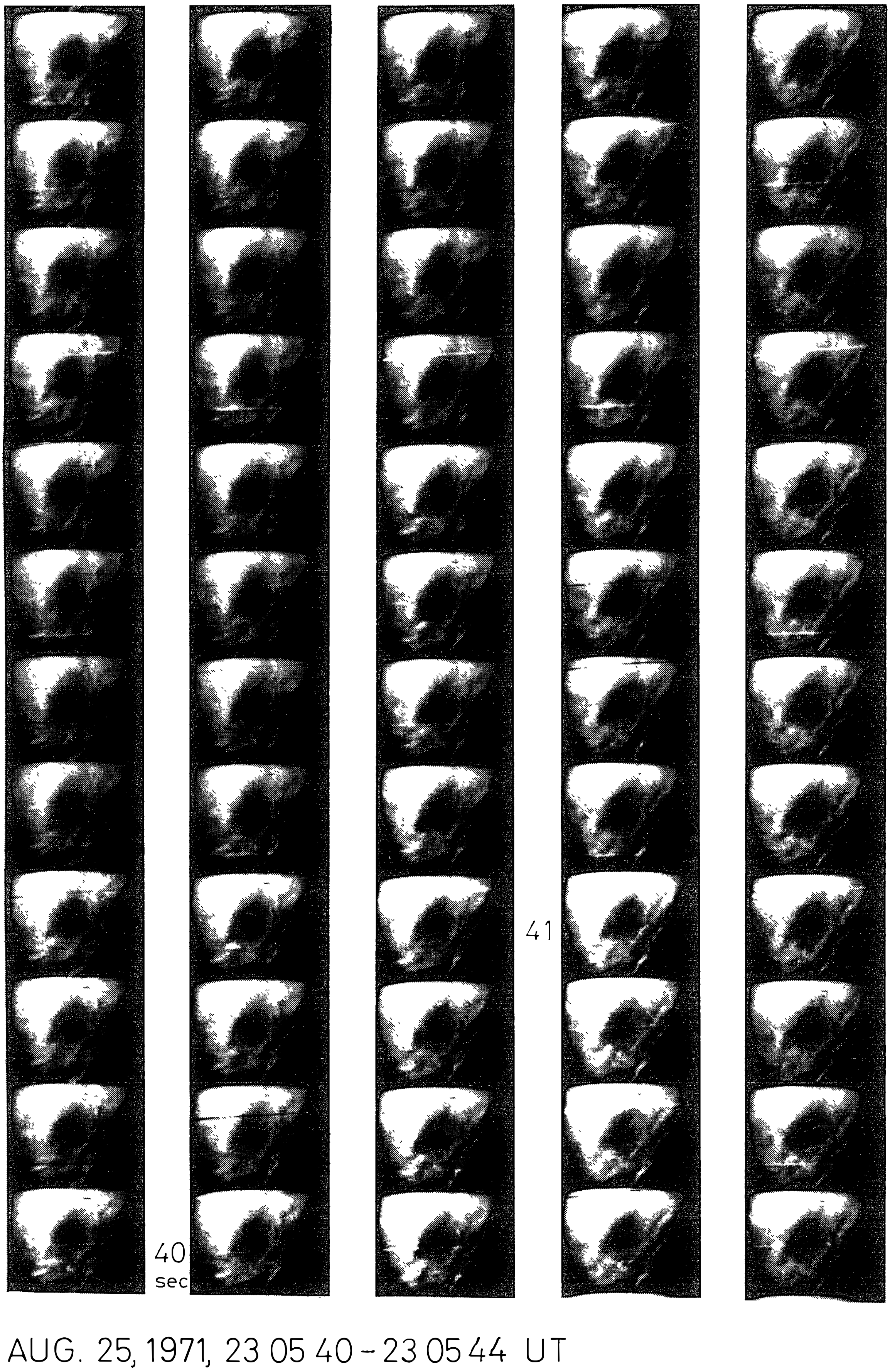


Fig. 24–1

Fig. 24. An example of ripple mode aurora viewed along the magnetic field. Small patches are seen in the↗

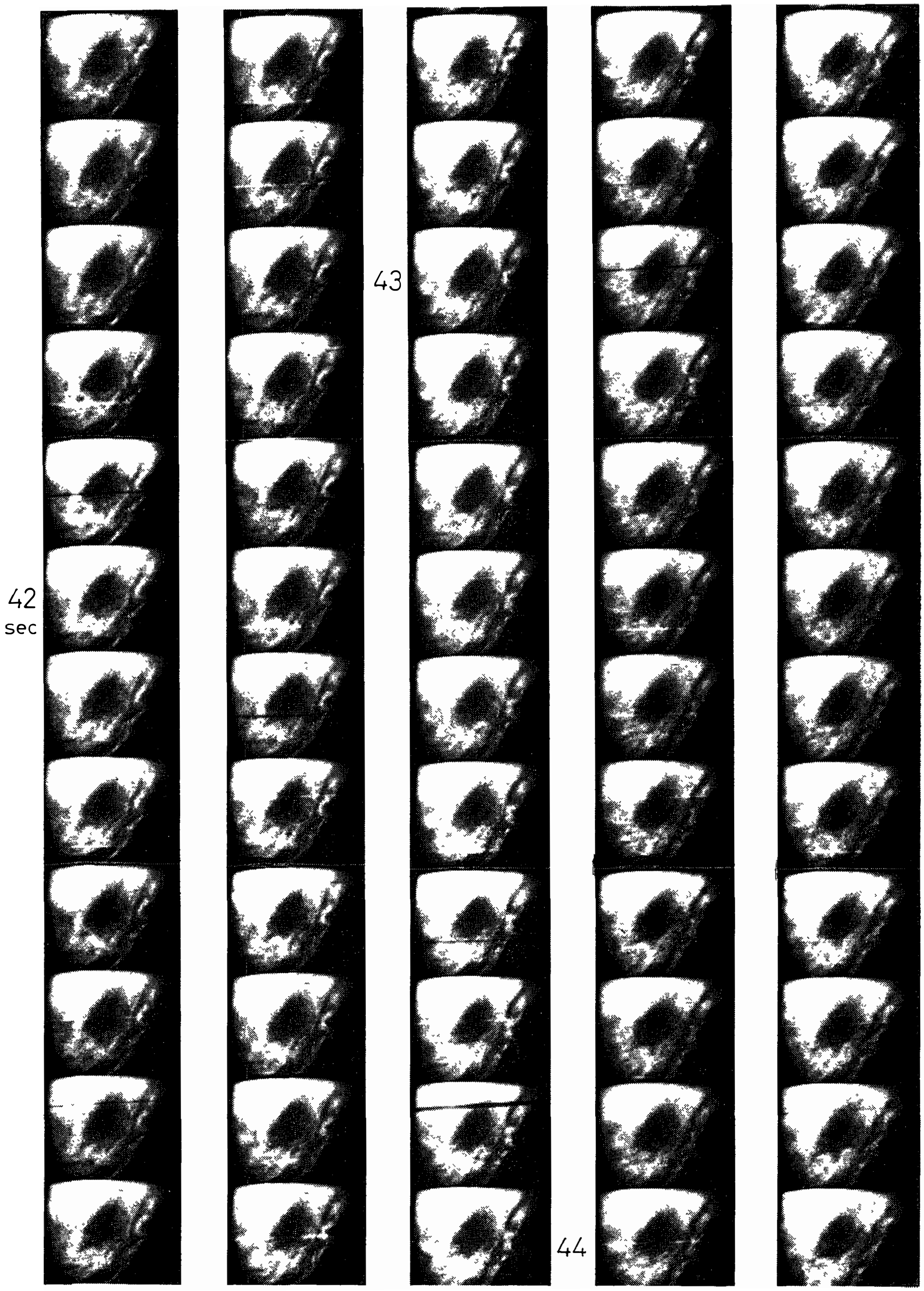


Fig. 24–2

↘lower left-hand side, of which some are stationary and some other flicker, resembling ripple. The latter seems to periodically rotate around the stationary patches. The center of the frame is nearly directed to magnetic zenith. The top is to the magnetic south and right is to the magnetic east.

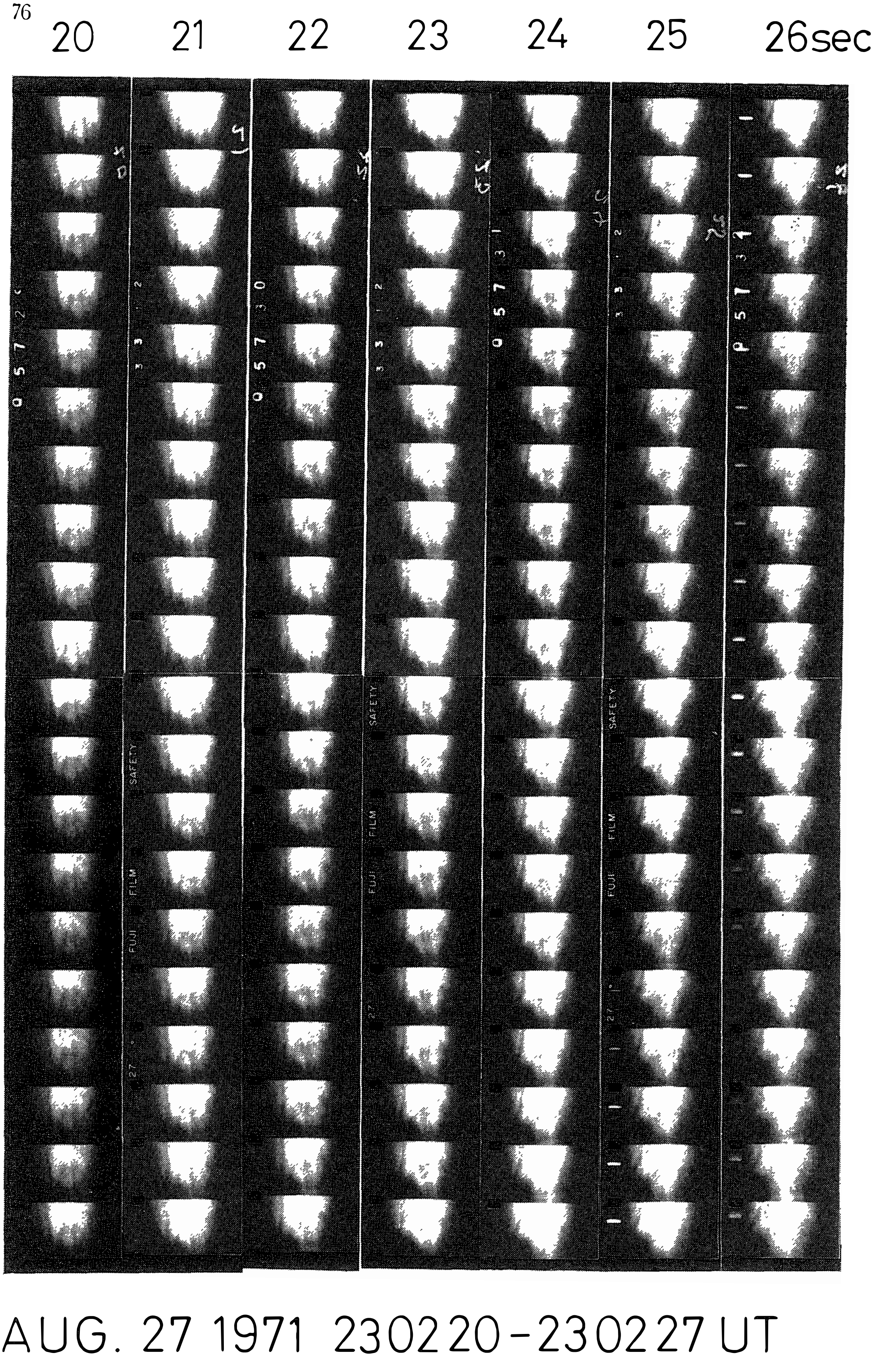
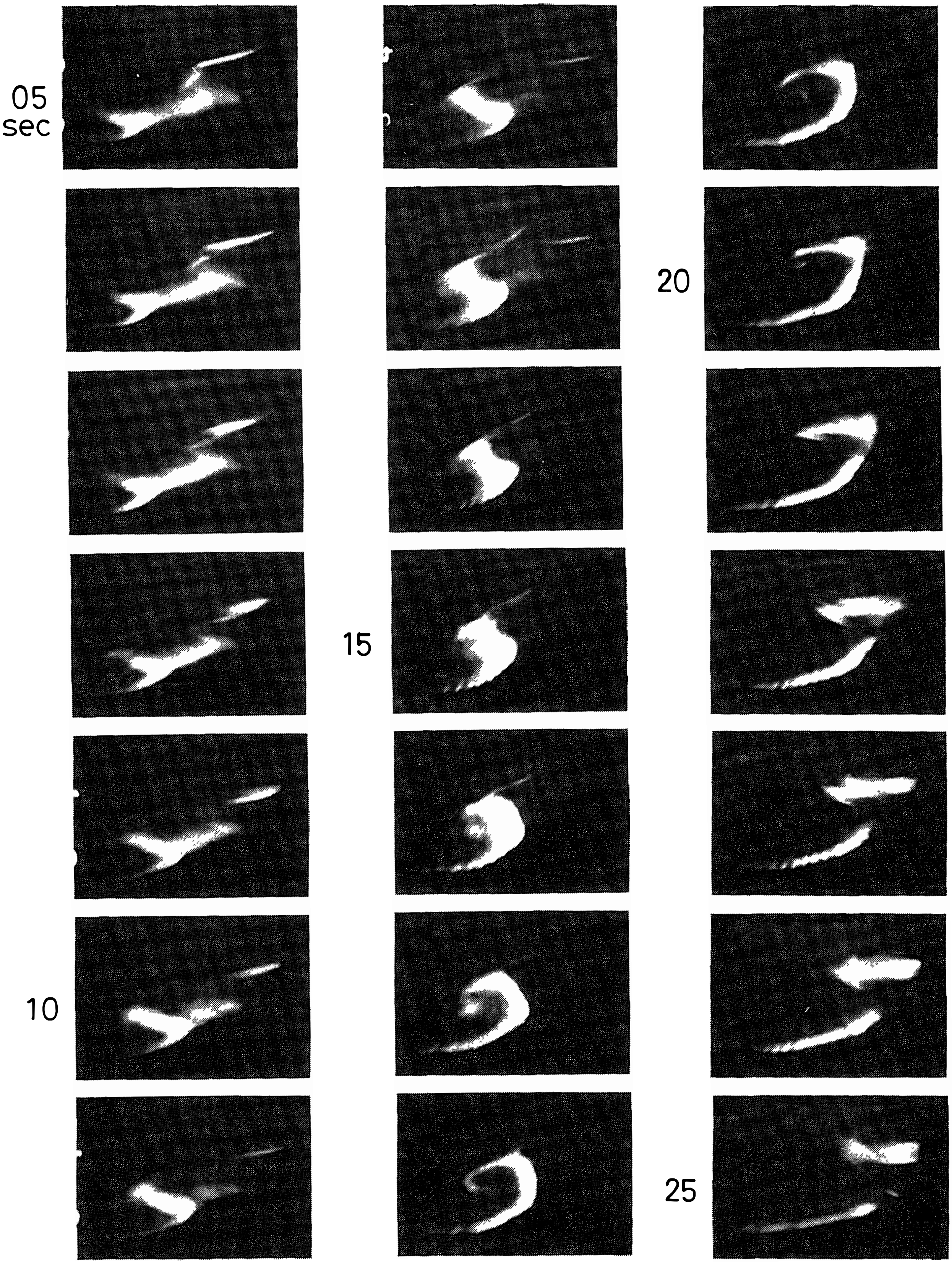


Fig 25. An example of ripple mode aurora viewed perpendicularly to the magnetic field. The patches viewed along the magnetic field are found to actually be flickering or rotating, extended ray structures along the magnetic field. The viewing angle is magnetic south near zenith. The top is to the magnetic north and right is to the magnetic west Ripple aurora generally appears in travelling surges and in active auroral folds



JUNE 26 1971 004905-004925 UT

Fig. 27. An example of Caterpiller tread-like expansion, leading to a flame-like structure The mode resembles growing of fern frond. The center of the field is almost to the magnetic zenith. Top is to the magnetic south and right is to the magnetic east. Flame-like structure is generally seen at the shrinking site of sheet auroral activity.

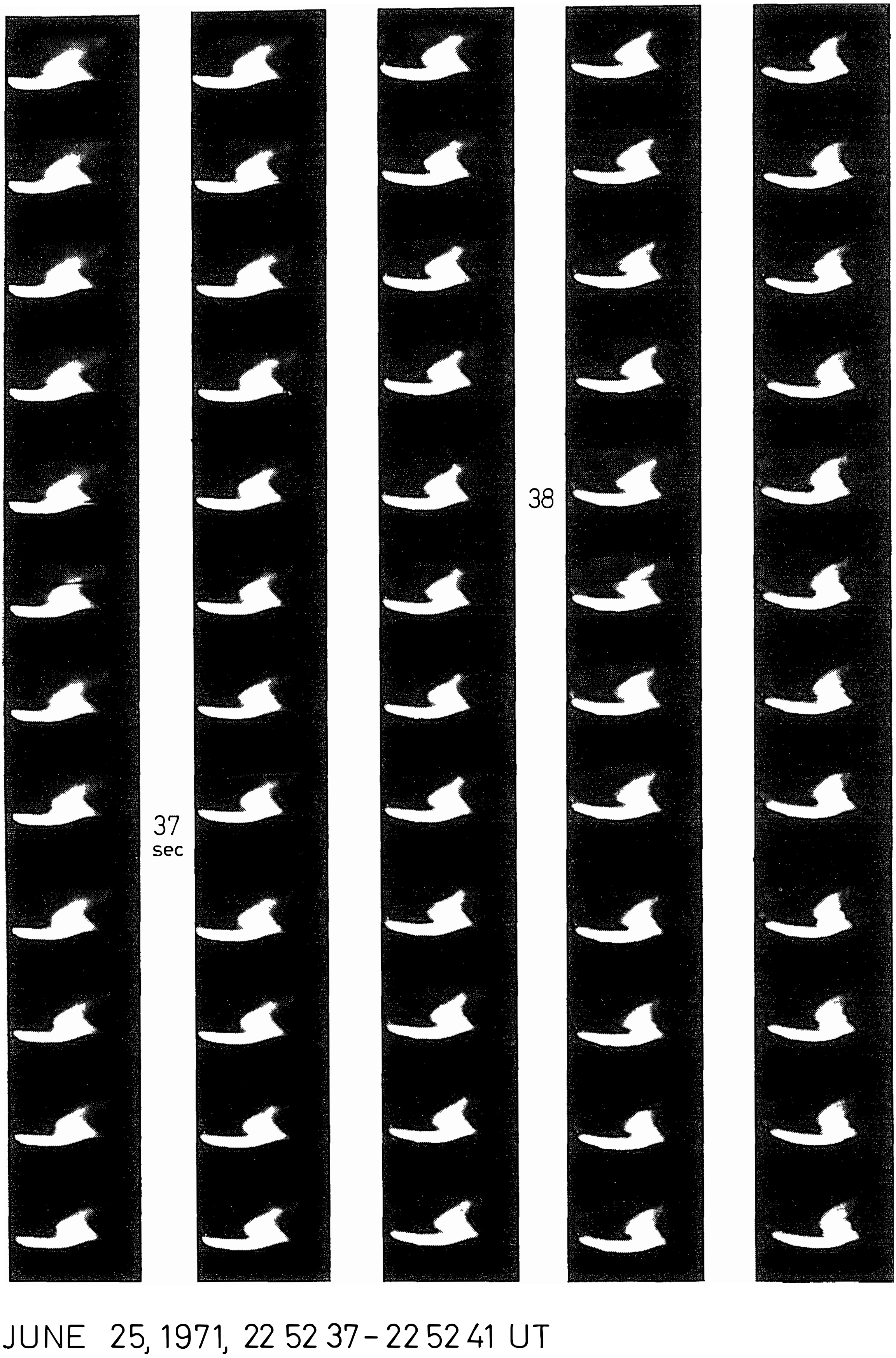


Fig 29-1

Fig. 29. This is a variation of flame structure, but apparently different. The pattern is not like flame,↗

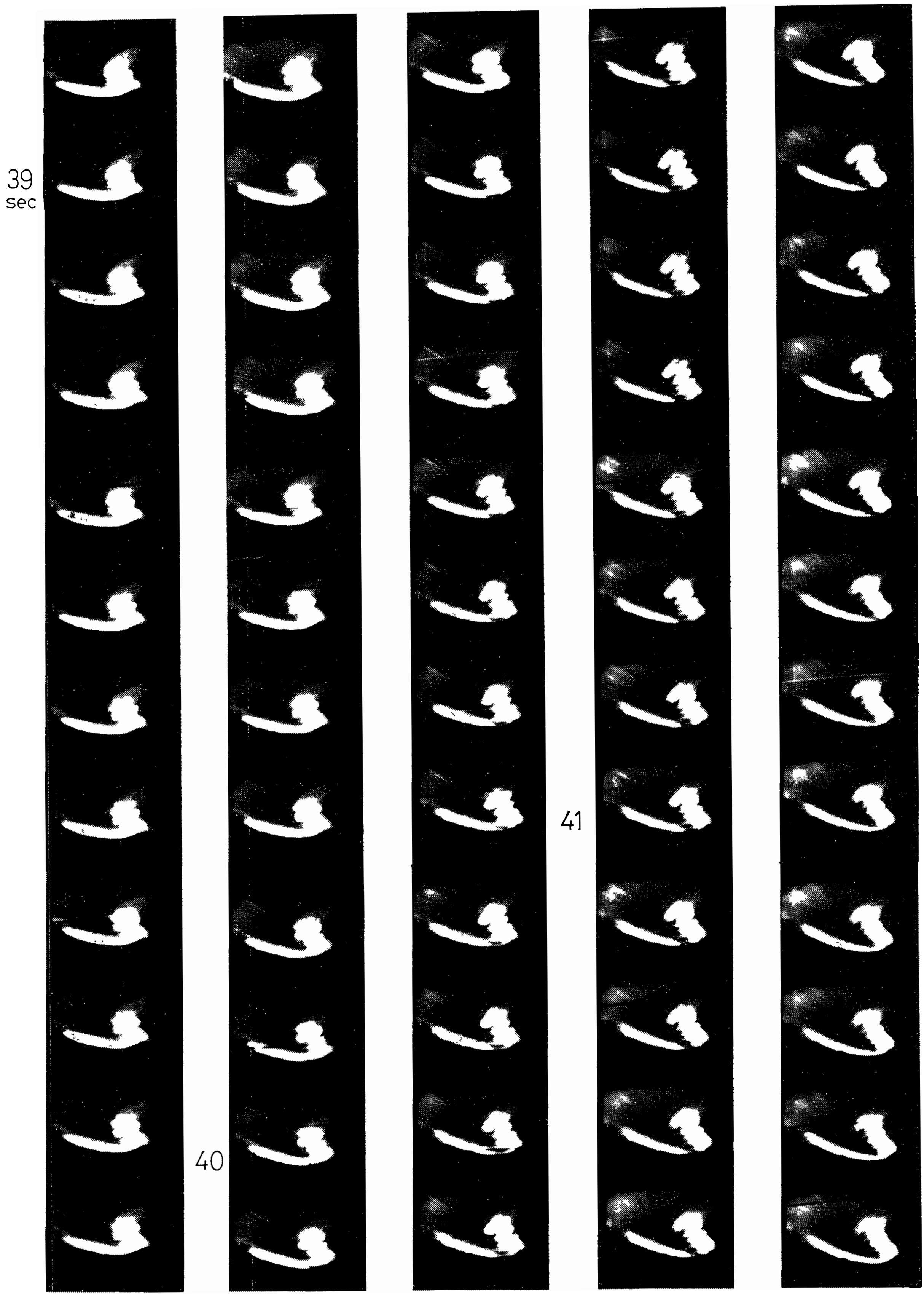


Fig. 29–2

↘*but it resembles cake decoration lettering using a cream sqeezer. The frame center is almost to the magnetic zenith. The top is to the magnetic south and right is to the magnetic east.*

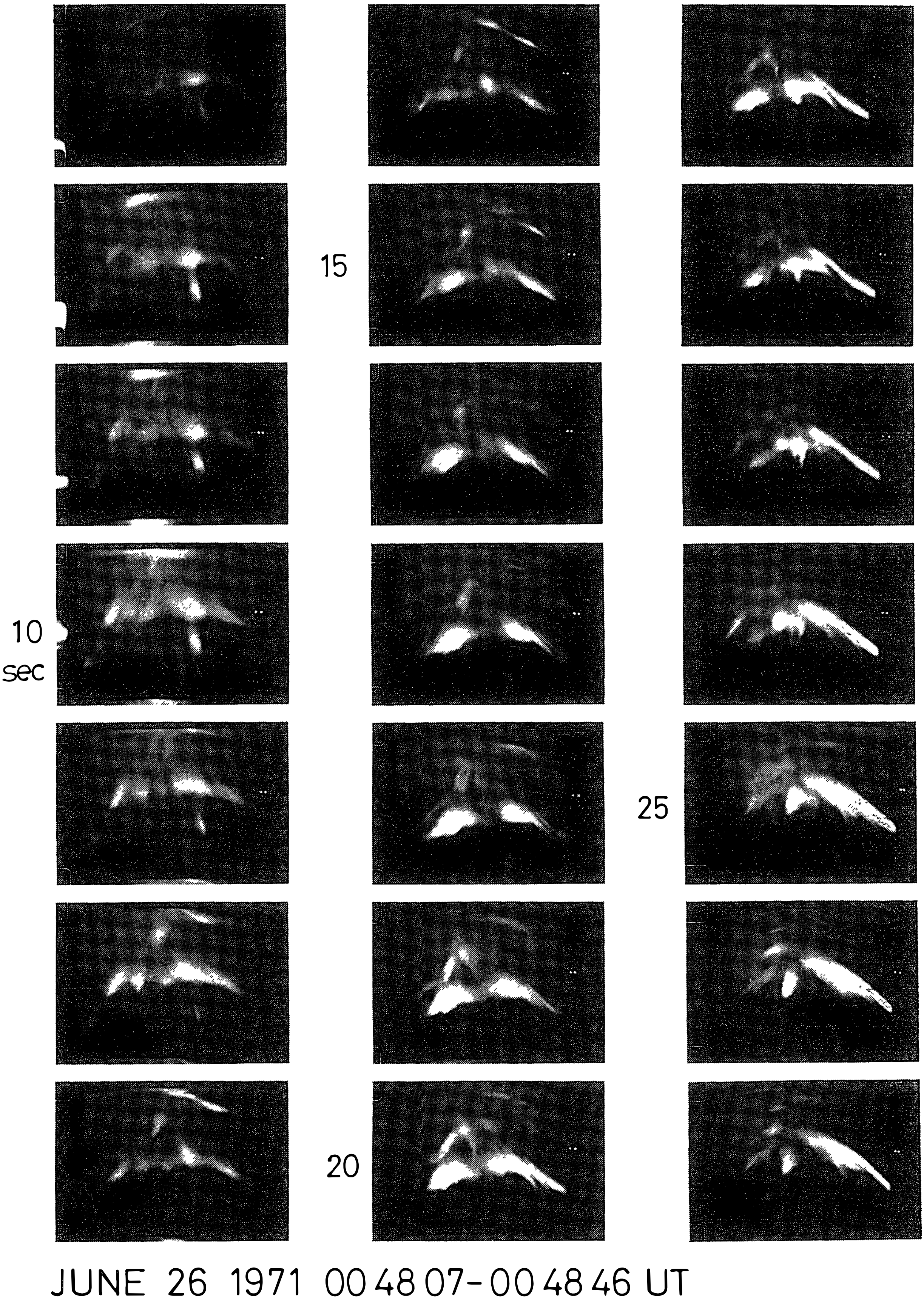


Fig 30-1

Fig. 30. When a flame-like structure appears around a sharp turning point of a sheet aurora, it tends to be↗

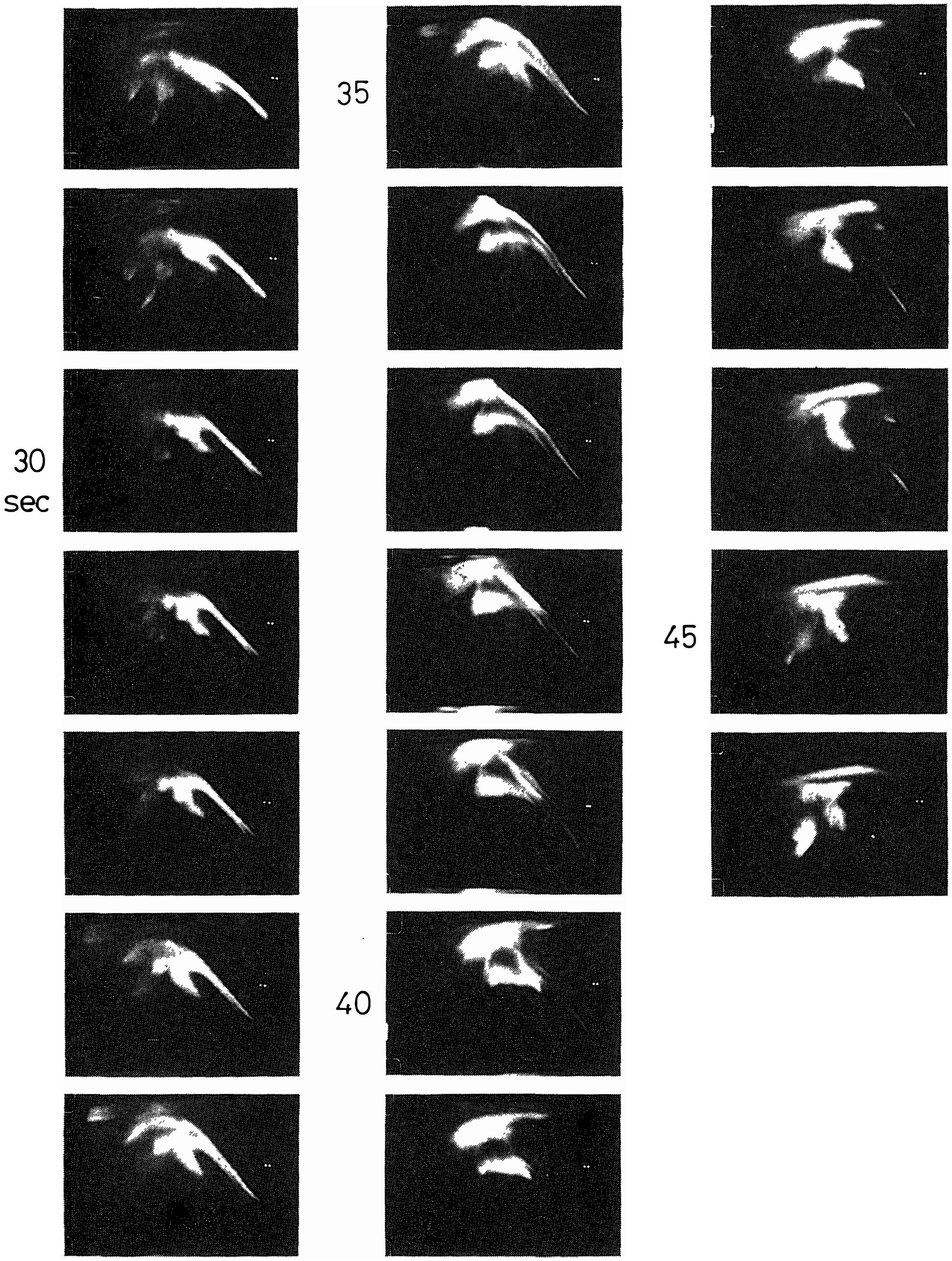


Fig. 30–2

a palm-like structure as seen at 004833 through 004840. This is one of the modes of corona formation. Near the magnetic zenith. Top is to the magnetic south, and right is to the magnetic east.

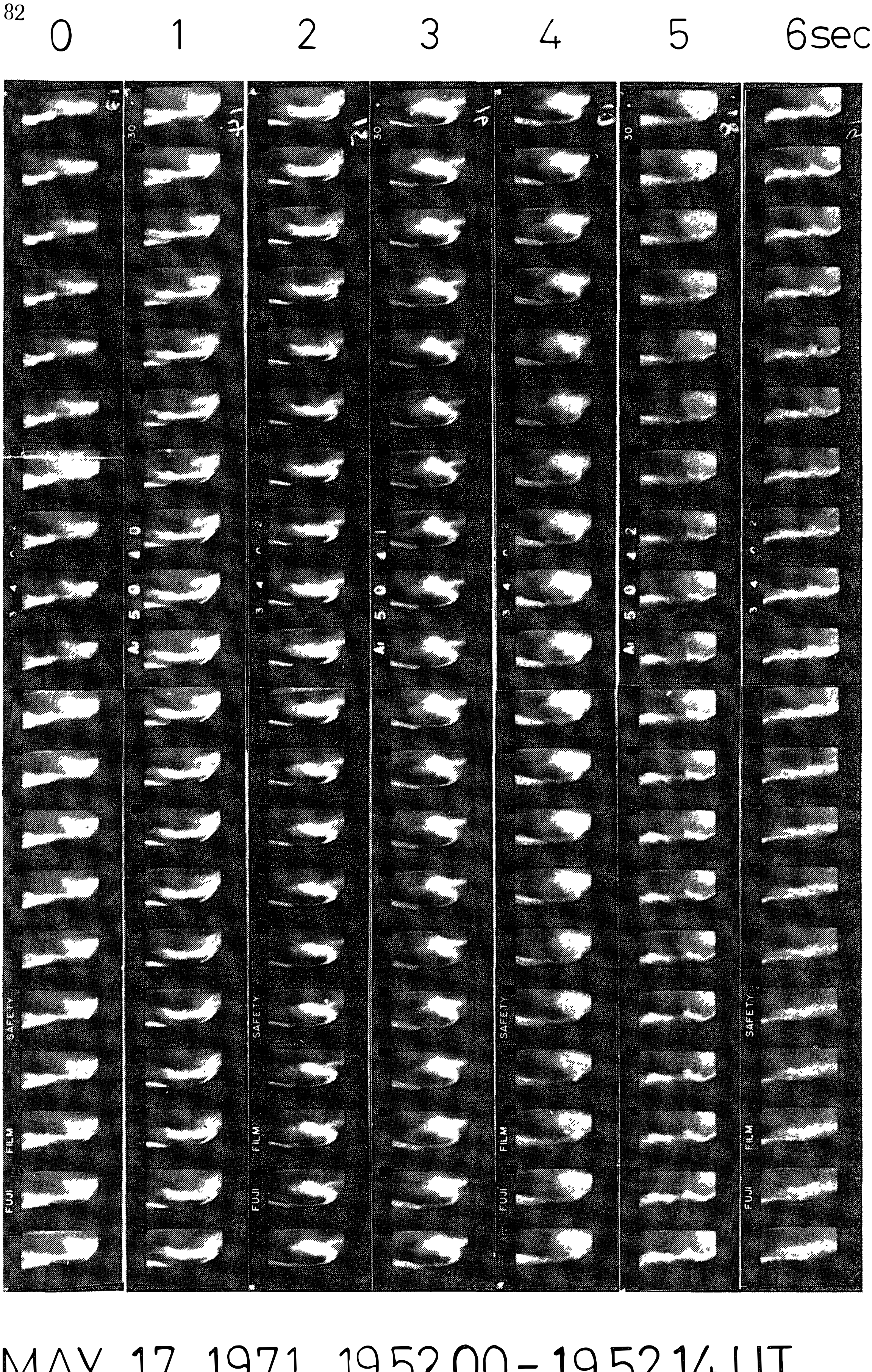


Fig 31-1

Fig 31 Sheet aurora sometimes eruptively splits into fine striation structures as seen at 195202.5, 195209.5↗

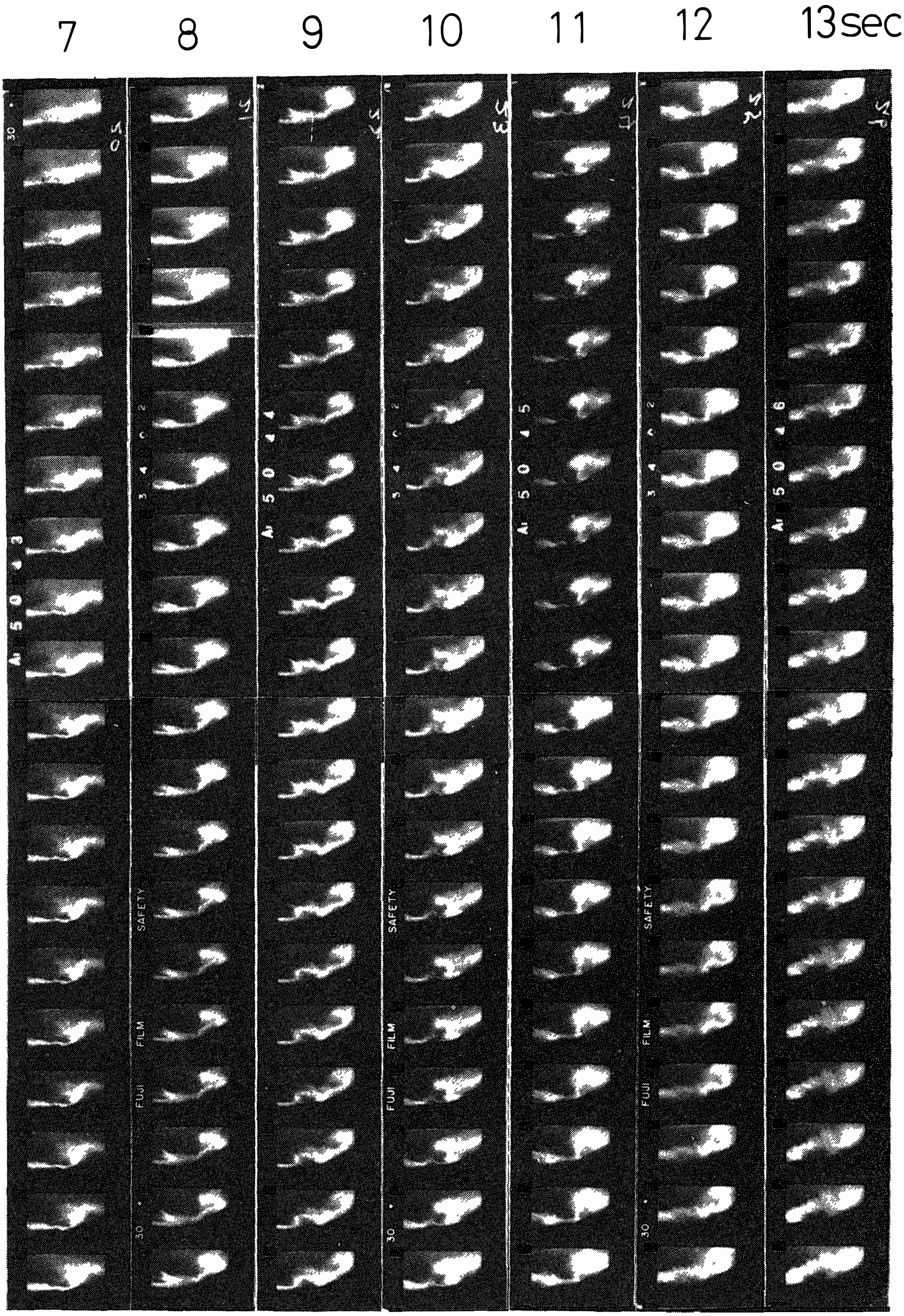


Fig. 31–2

↘and 195213. This may be regarded as an example either of the flame-structure, or of multiple protrusive splittings. The center of the frame is approximately to the magnetic zenith. The top is to the magnetic south and right is to the magnetic east. This mode is often seen near high latitude border of aurora in the dusk sector on an active day.

satellite
1119 UT
NOV 28
1971

TV
004848.5 UT
JUNE 26
1971

TV
004920.5 UT
JUNE 26
1971

Fig. 32. Comparison between flame structure formation (middle and bottom pictures) and cusp-like S-pattern formation (top picture) These are found to be essentially the same.

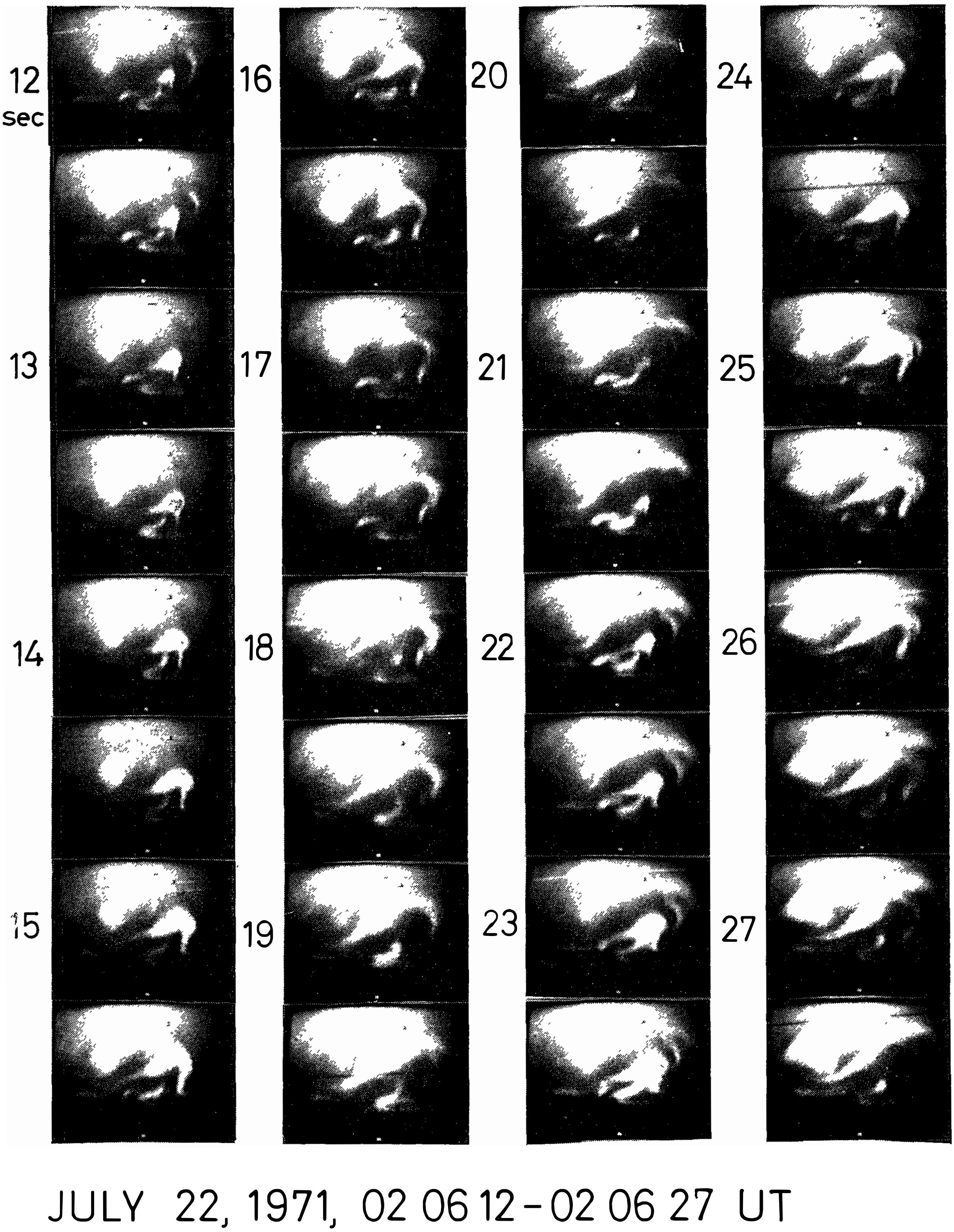
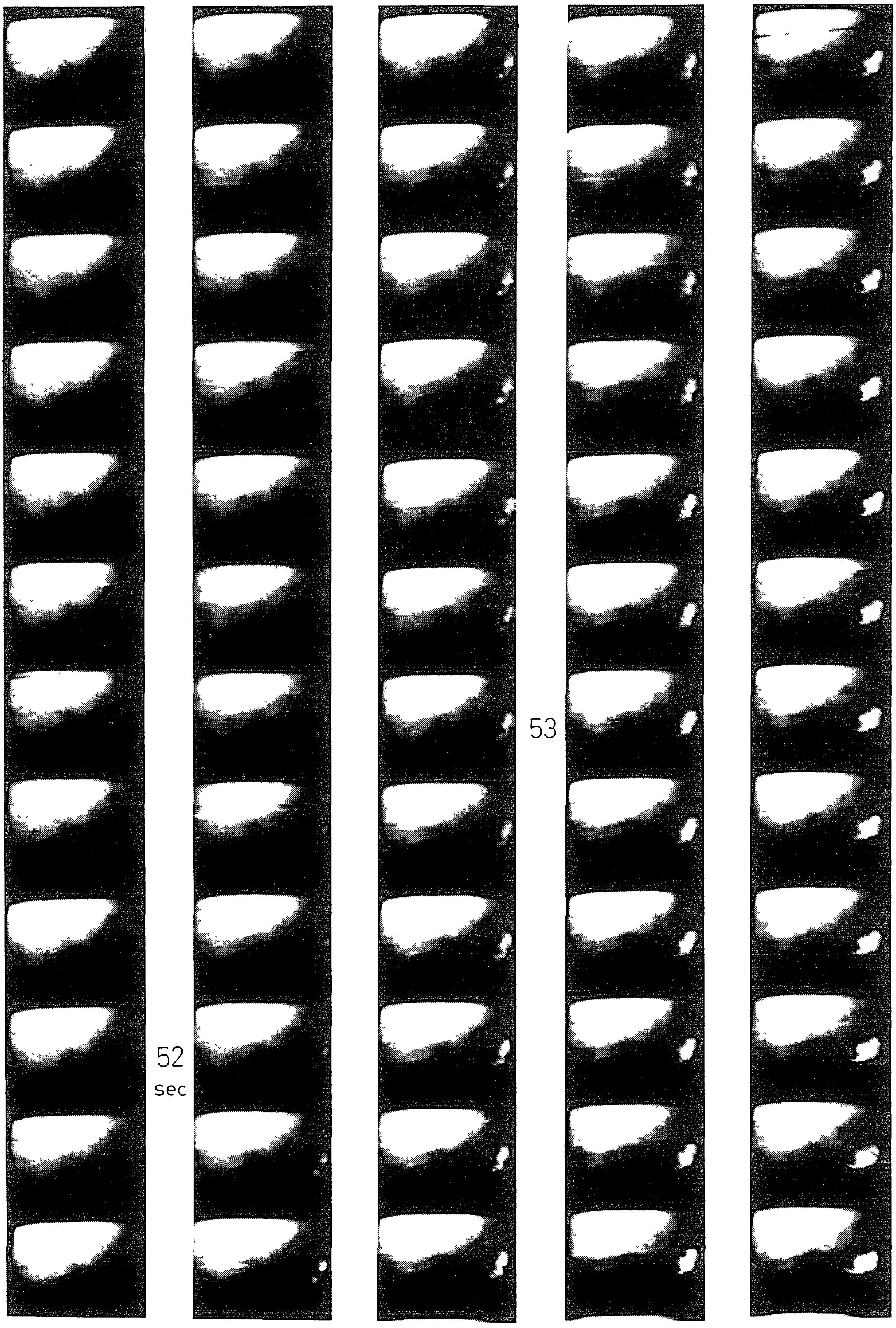


Fig. 37. Typical example of a quasi-periodic sequential switching aurora. Almost the same pattern appears repeatedly with a period of about 10 sec. The direction of propagation of switch-on area is statistically poleward (upward). Magnetic north near horizon. The top is to the magnetic south and right is to the magnetic east.



AUG. 25, 1971, 23 23 52 - 23 23 56 UT

Fig. 33–1

Fig 33. Trailing rotations sometimes appear very abruptly, propagating parallel to the main arc This is↗

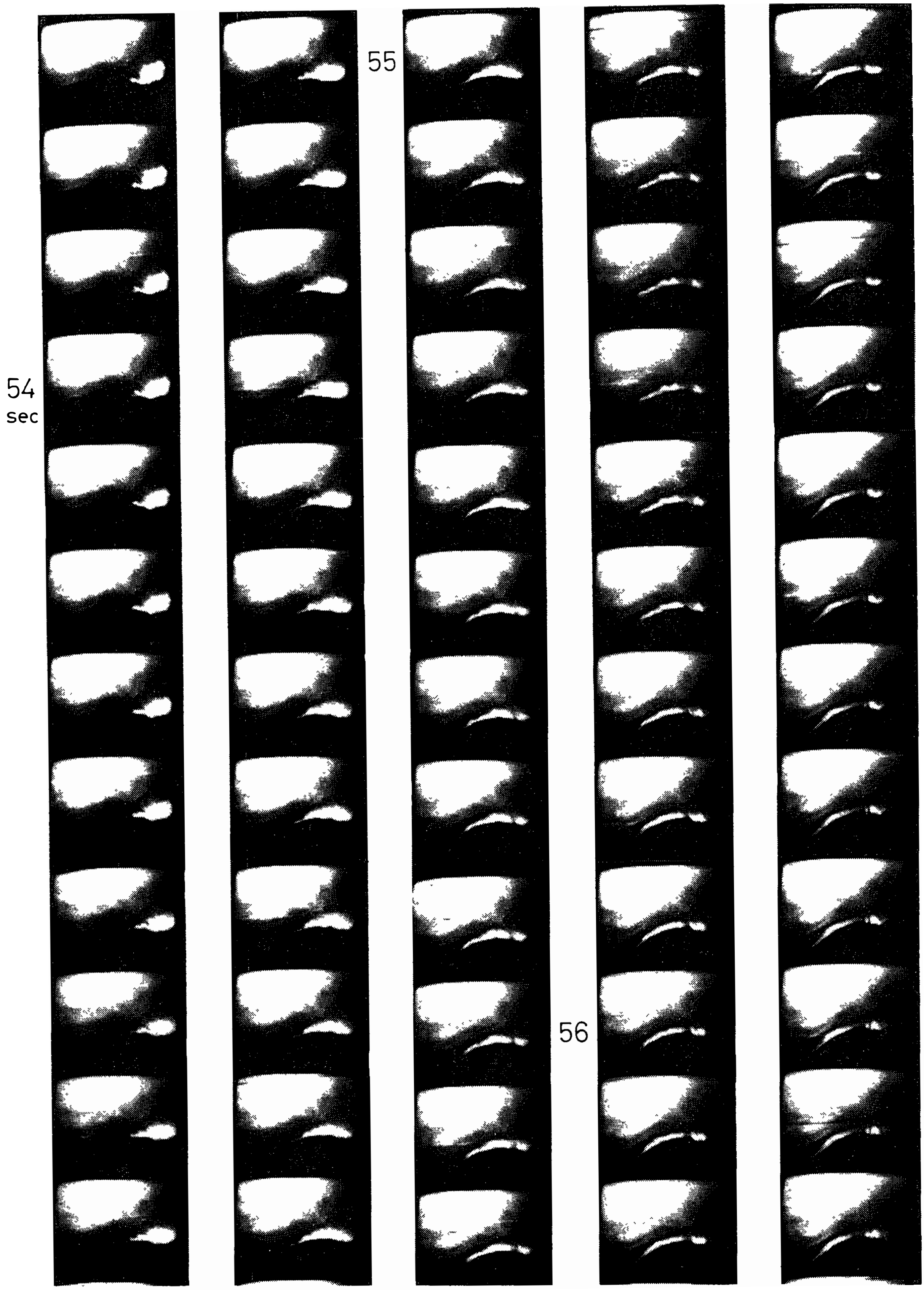


Fig. 33–2

↘*an example associated with VLF chorus emissions near the magnetic zenith. The top is to the magnetic S–E and right is to the magnetic N–E.*

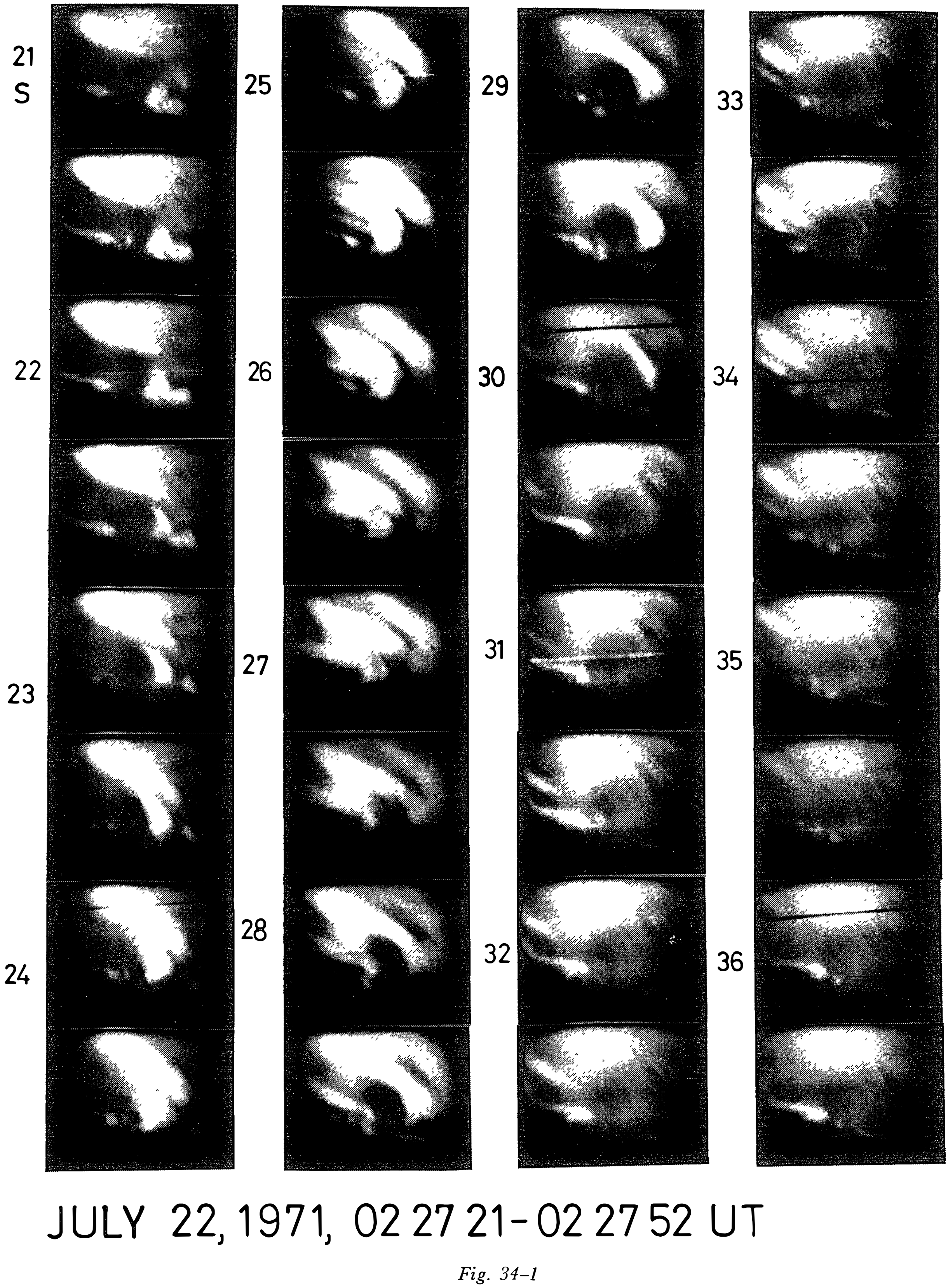


Fig. 34-1

Fig. 34. An example of quasi-periodic poleward propagating on-off switching striation and patches. The poleward shift or expansion, though it appears to be continuous, is really an intermittent stepwise↗

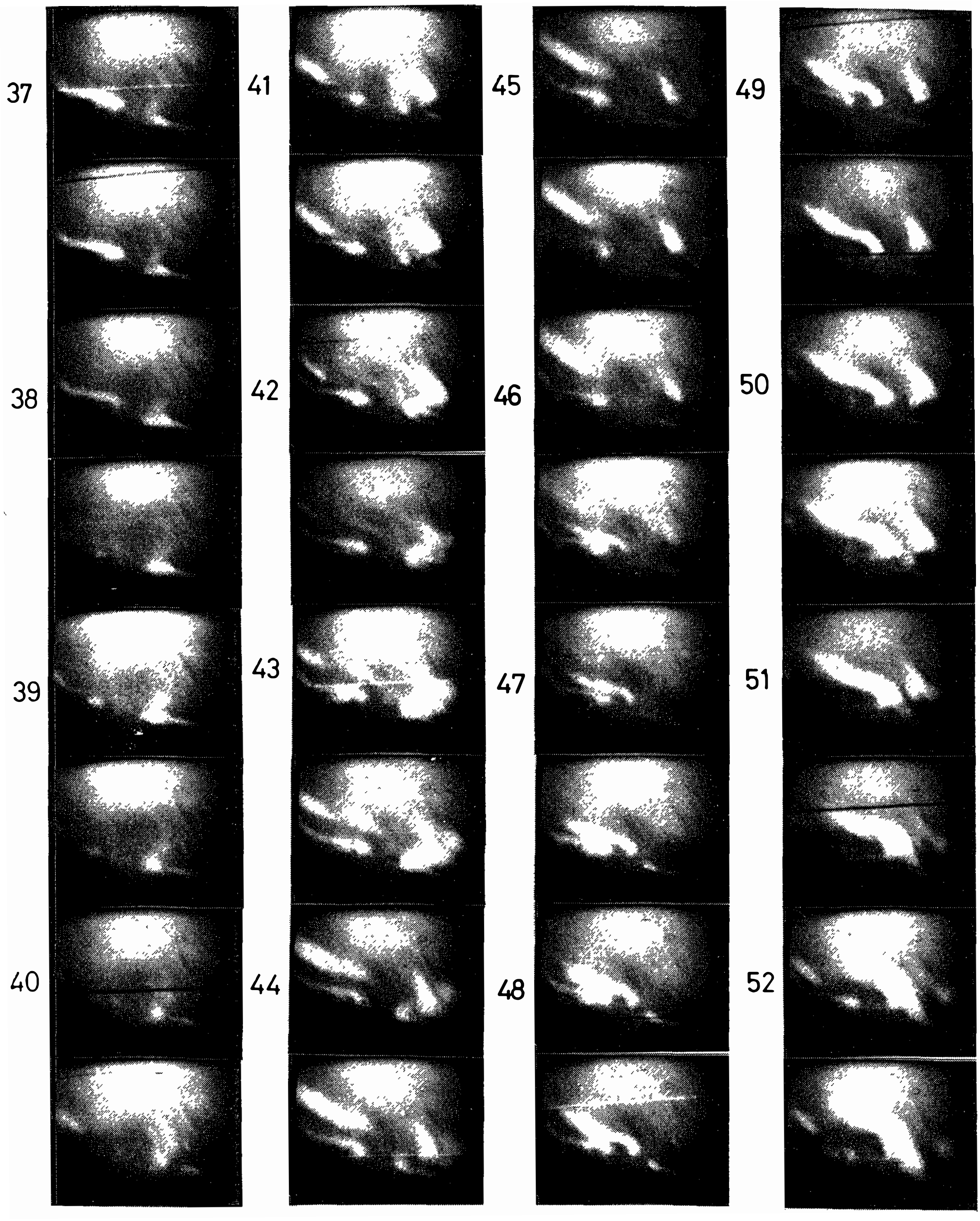
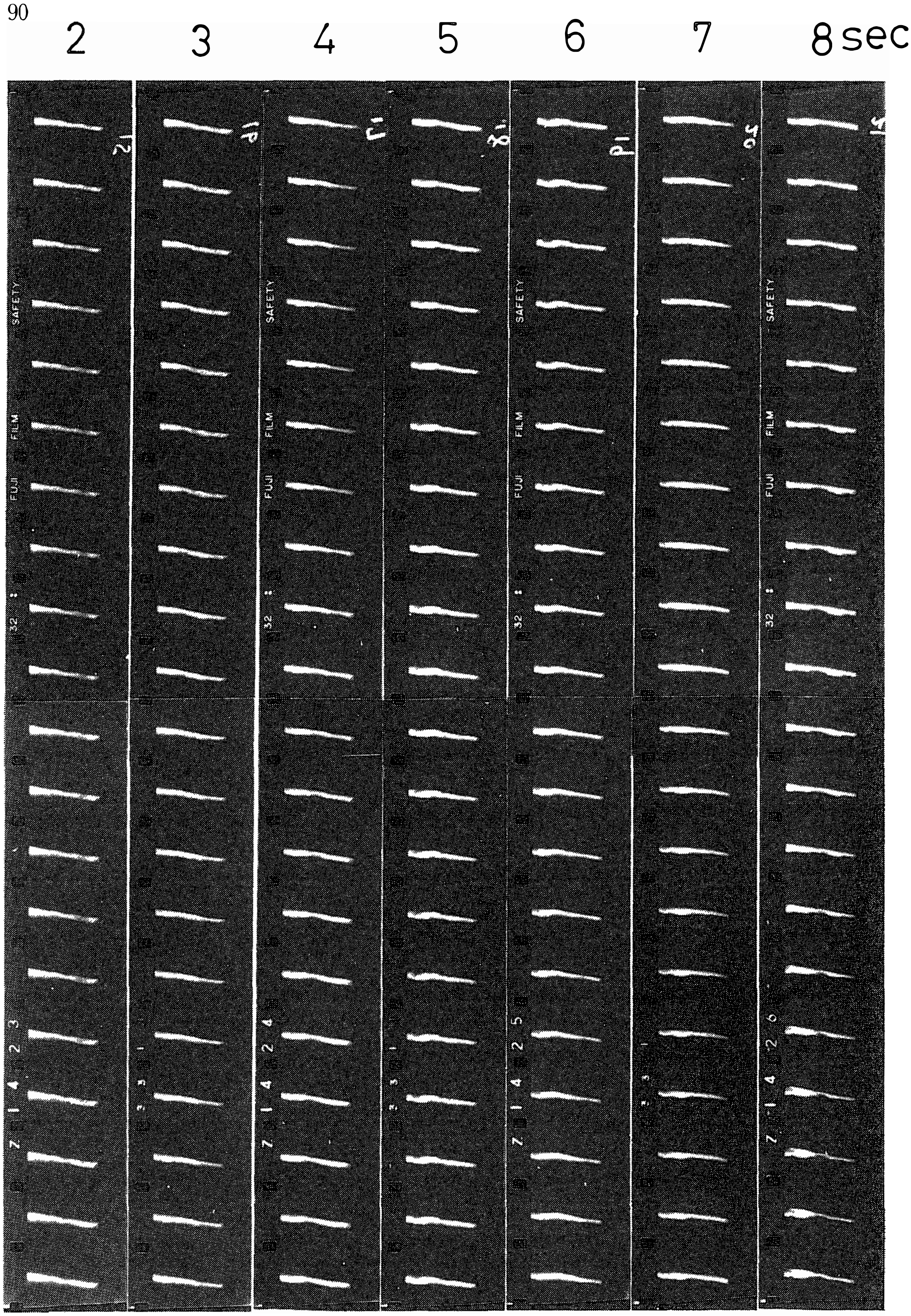


Fig. 34–2

↘shift of switch on regions. The periodicity is readily found by the fact that the whole pattern at 23 sec and that at 52 sec is approximately the same. Magnetic N–E near horizon. The top is to the magnetic S–W, and right is to the magnetic S–E. The direction of the shift or expansion is found to the magnetic south. This kind appears near the low latitude border of aurora after an auroral expansion mostly in the dawn sector.



MAY 17 1971 224502 – 224516 UT

Fig 35-1

Fig. 35. Bright spots often propagate along a thin sheet. The propagation direction changes from time to

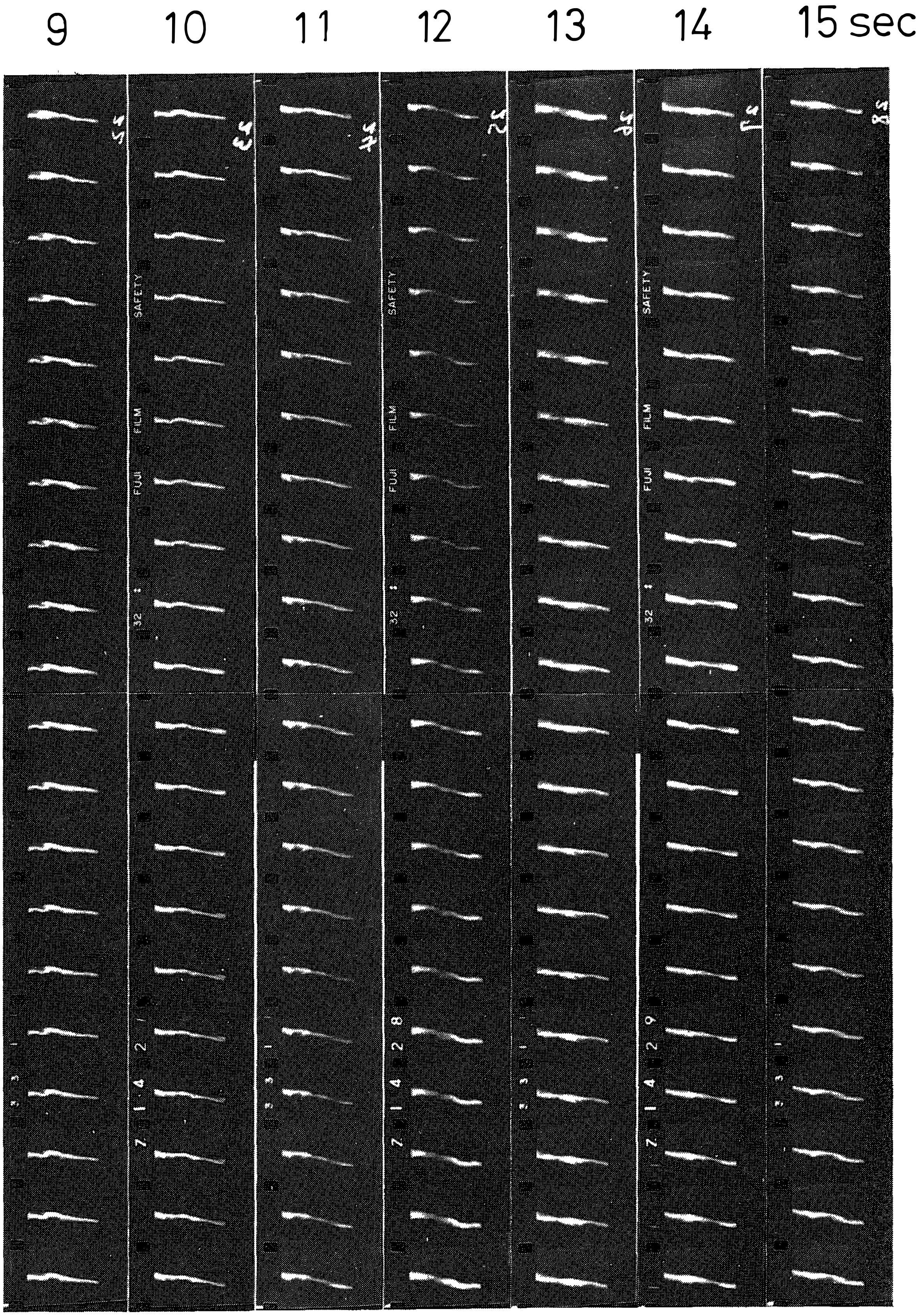


Fig. 35–2

time. Splitting of small scale often occurs just after the passage of the bright spot as seen at 224508.7 and 224513.2. The center is almost to the magnetic zenith. The top is to the magnetic south and right is to the magnetic east.

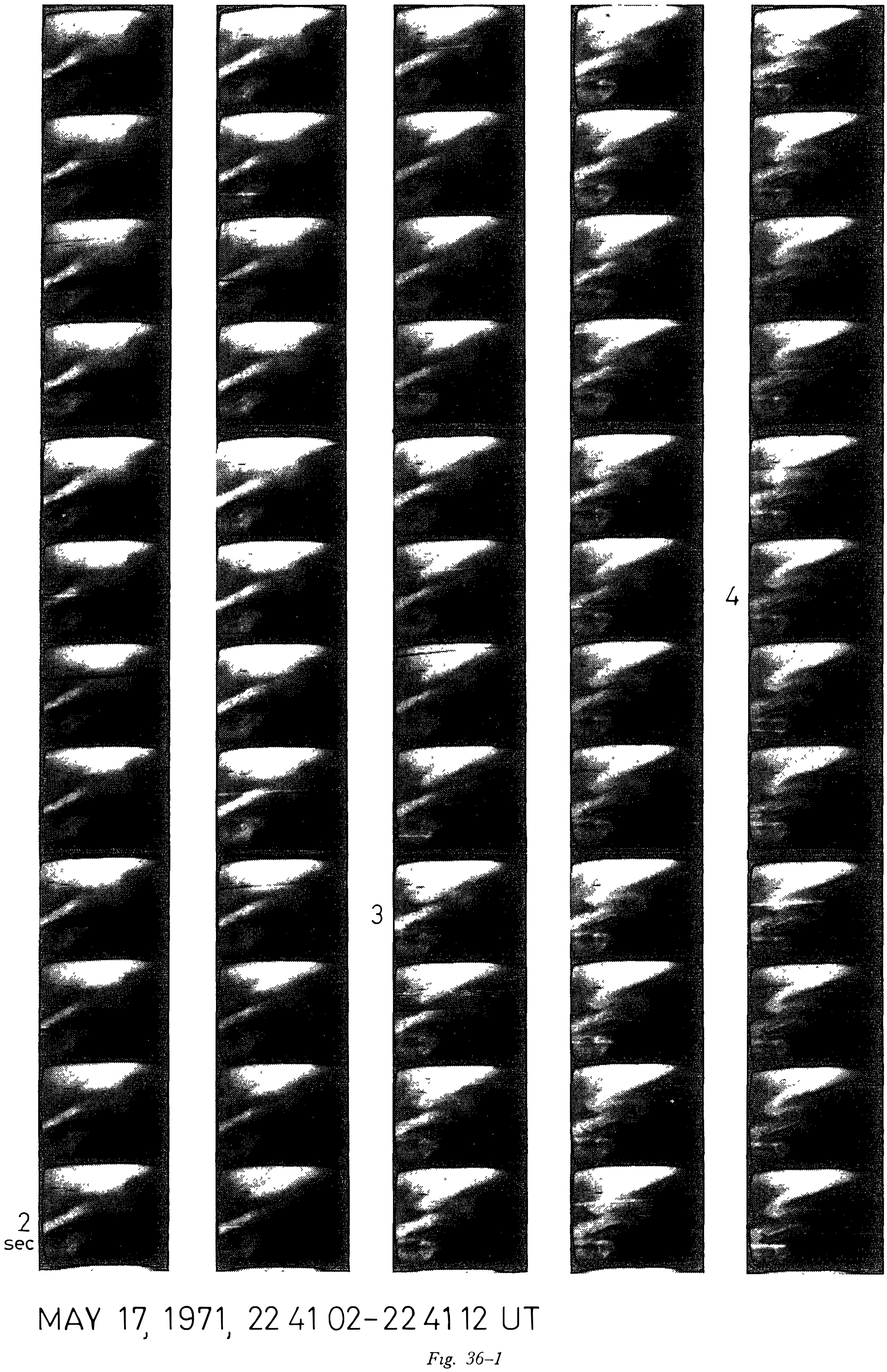


Fig. 36-1

Fig. 36. Drift sometimes is quite irregular. It changes its direction and speed from time to time and from↗

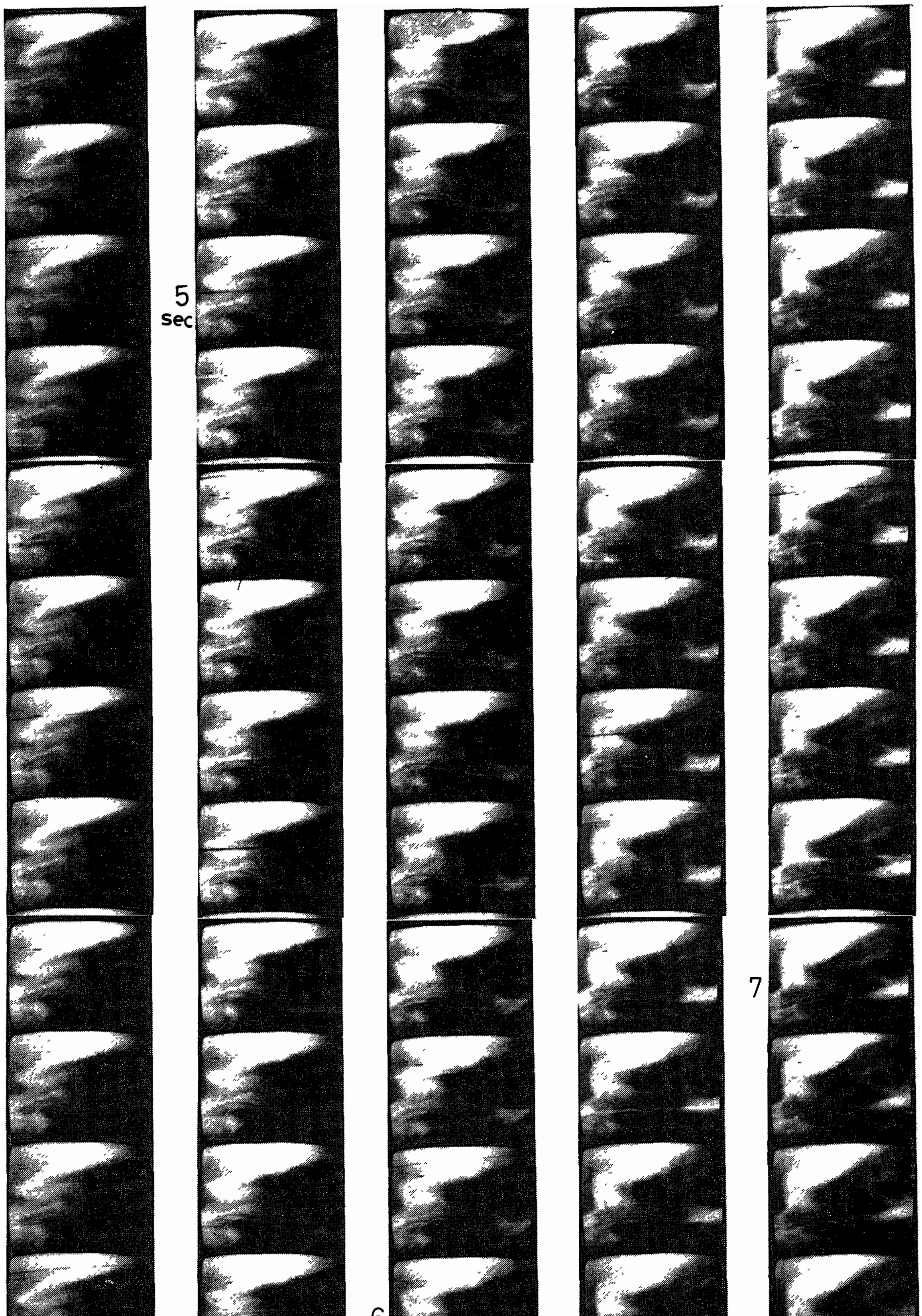


Fig. 36–2

↘*place to place. This is a typical example of such an irregular drift. Nearly the magnetic zenith. Top is to the magnetic S–W and right is to the magnetic S–E.*

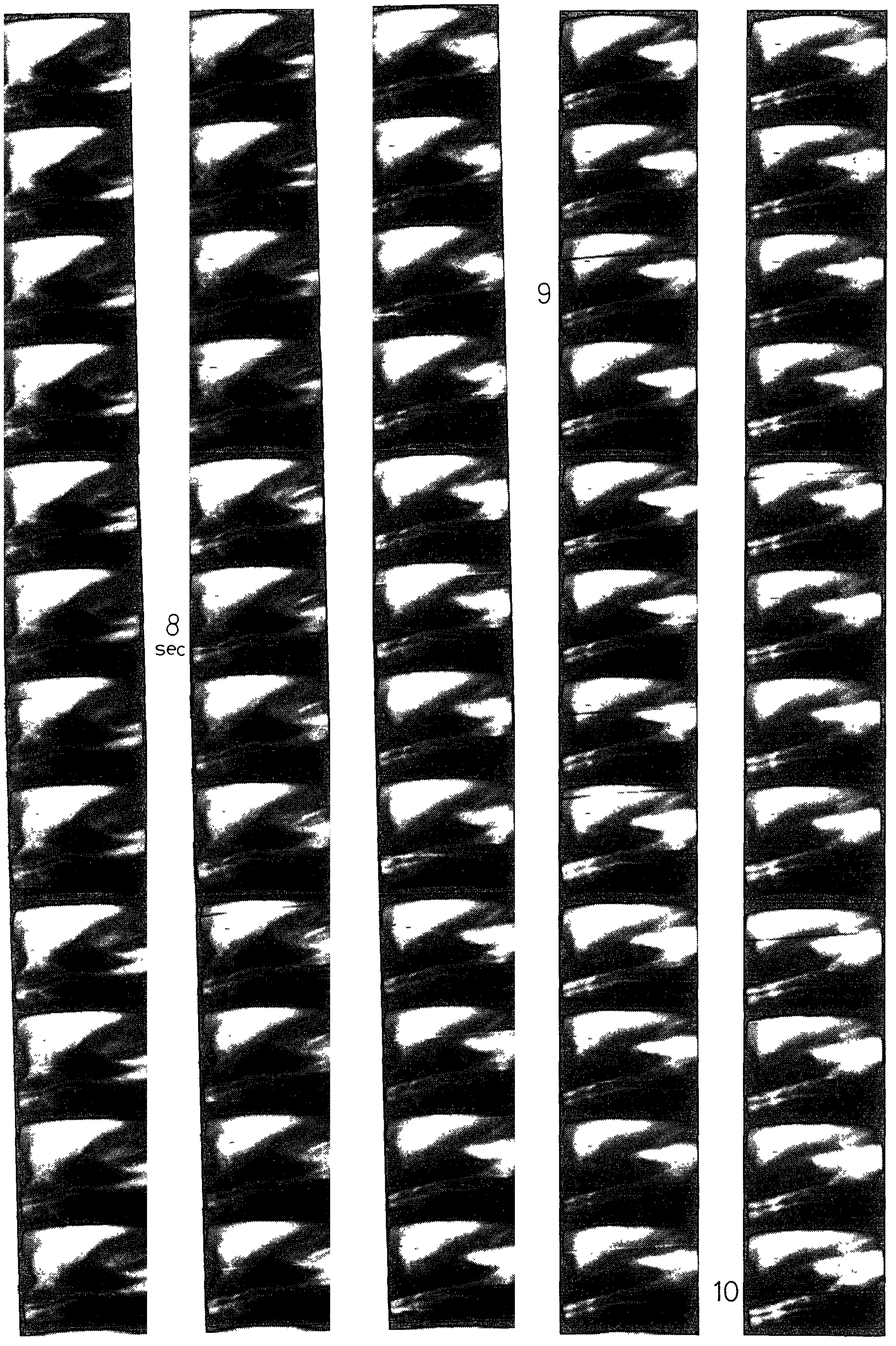


Fig. 36–3

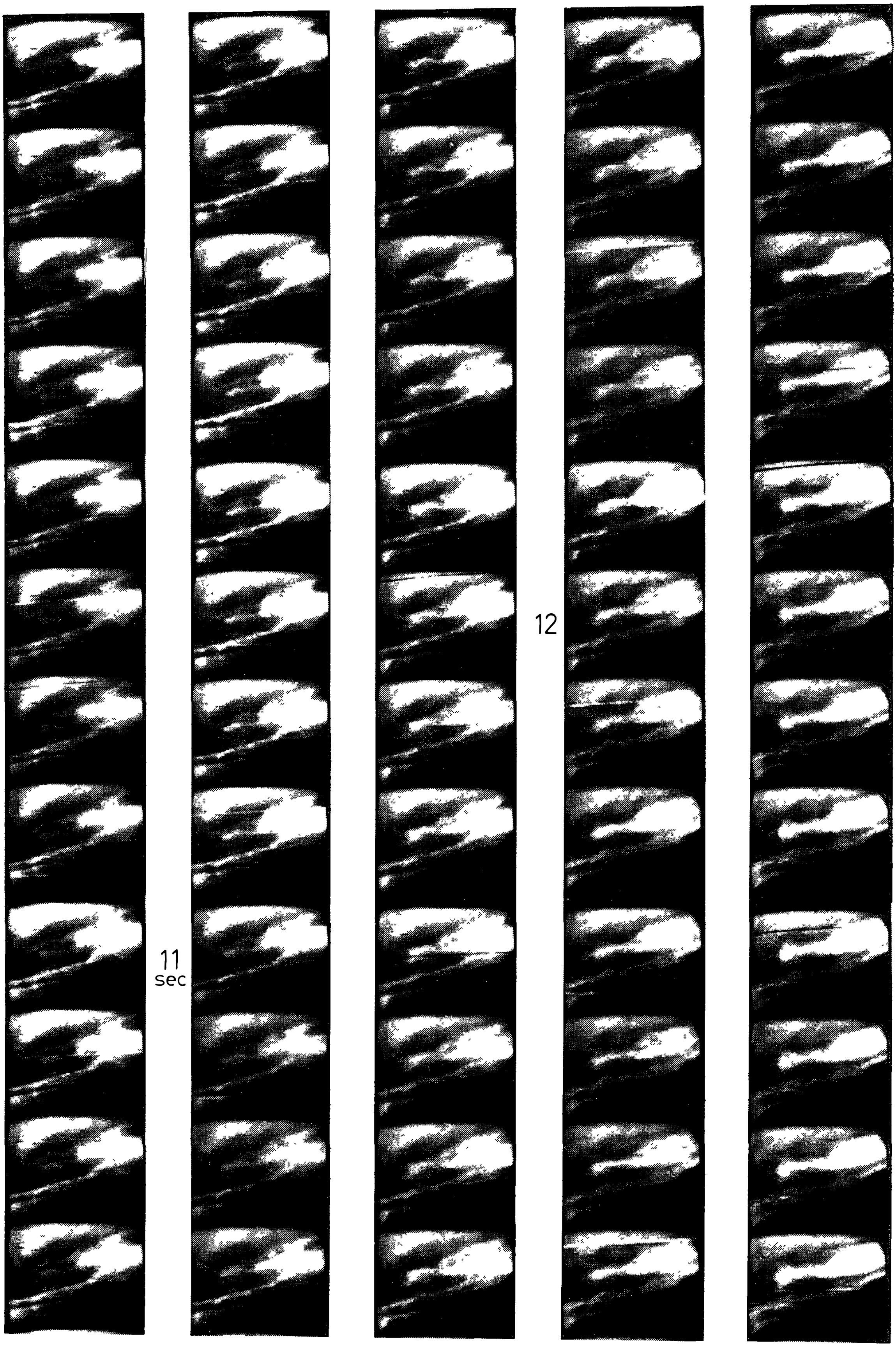
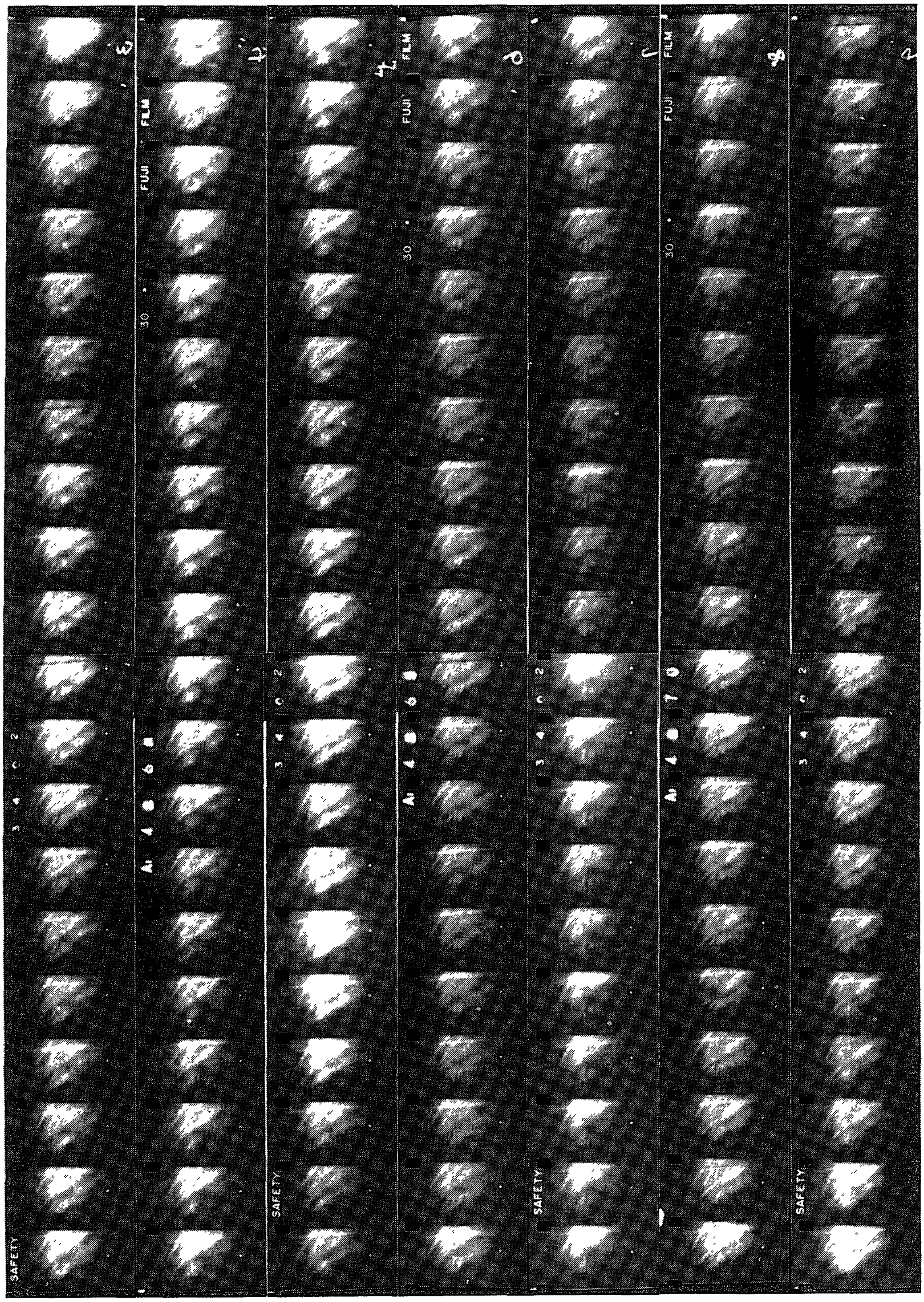


Fig. 36–4

27 28 29 30 31 32 33sec



JULY 22 1971 01 49 27 - 01 49 41 UT

Fig 38-1

Eig. 38. When an on-off switching aurora appears near the horizon, it sometimes appears to undulate, very↗

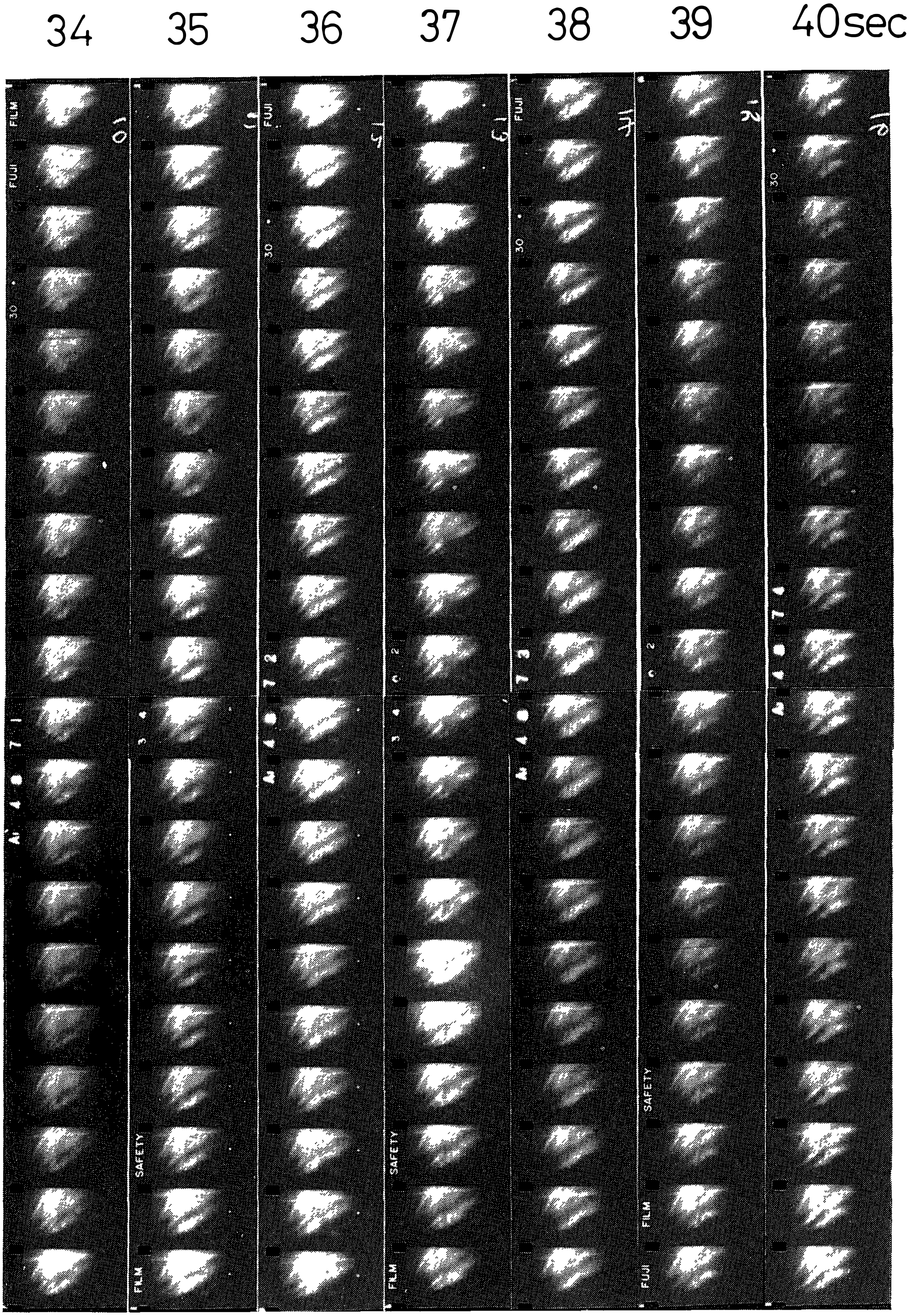
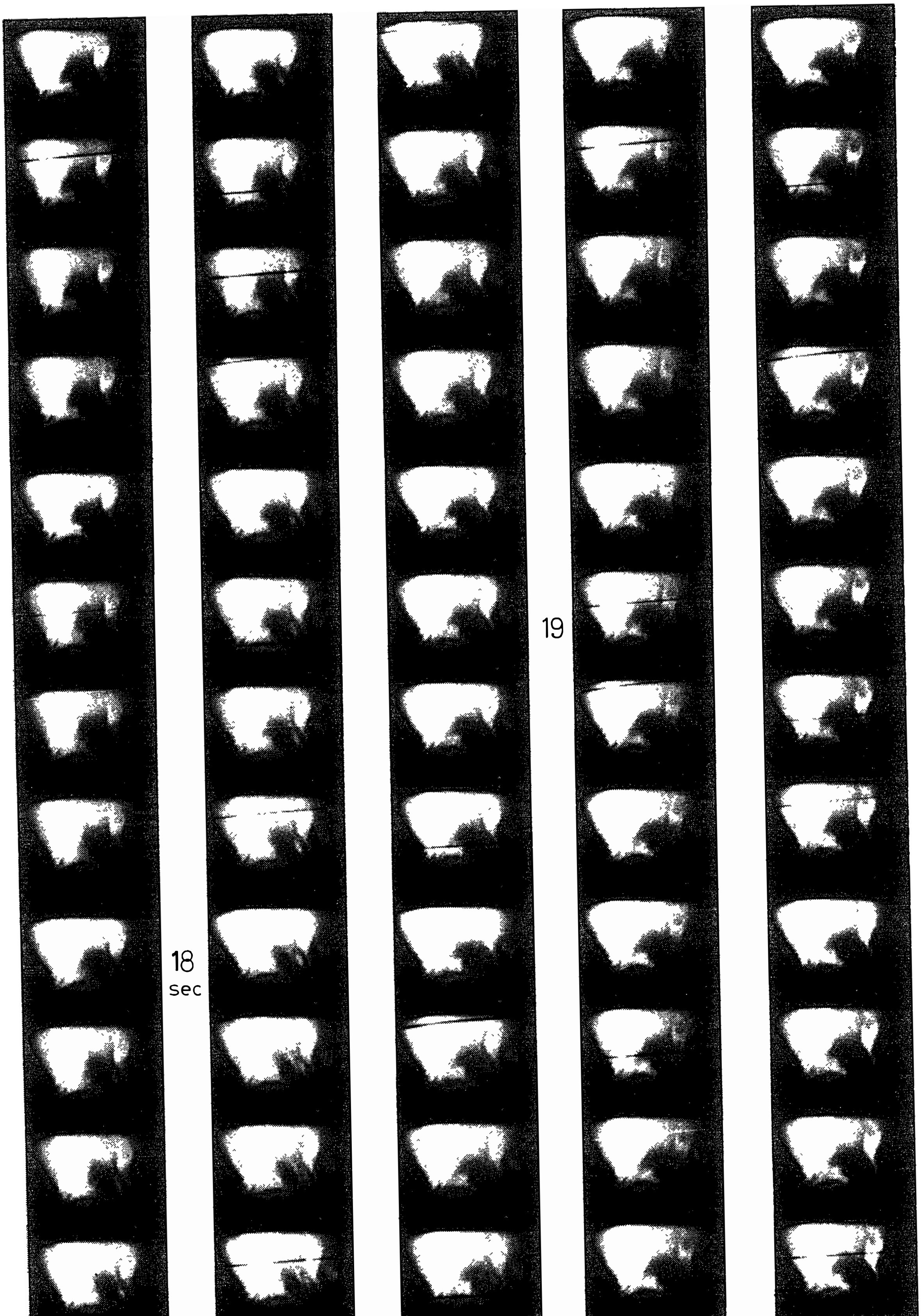


Fig. 38–2

↘*much resembling a waterplant in a brook. Magnetic N–W near horizon. The top is to the magnetic S–E and right is to the magnetic N–E.*



JULY 22, 1971, 01 46 18 - 01 46 22 UT

Fig. 39–1

Fig. 39. As a switching aurora is observed in the magnetic W–E direction near horizon, it is often has the↗

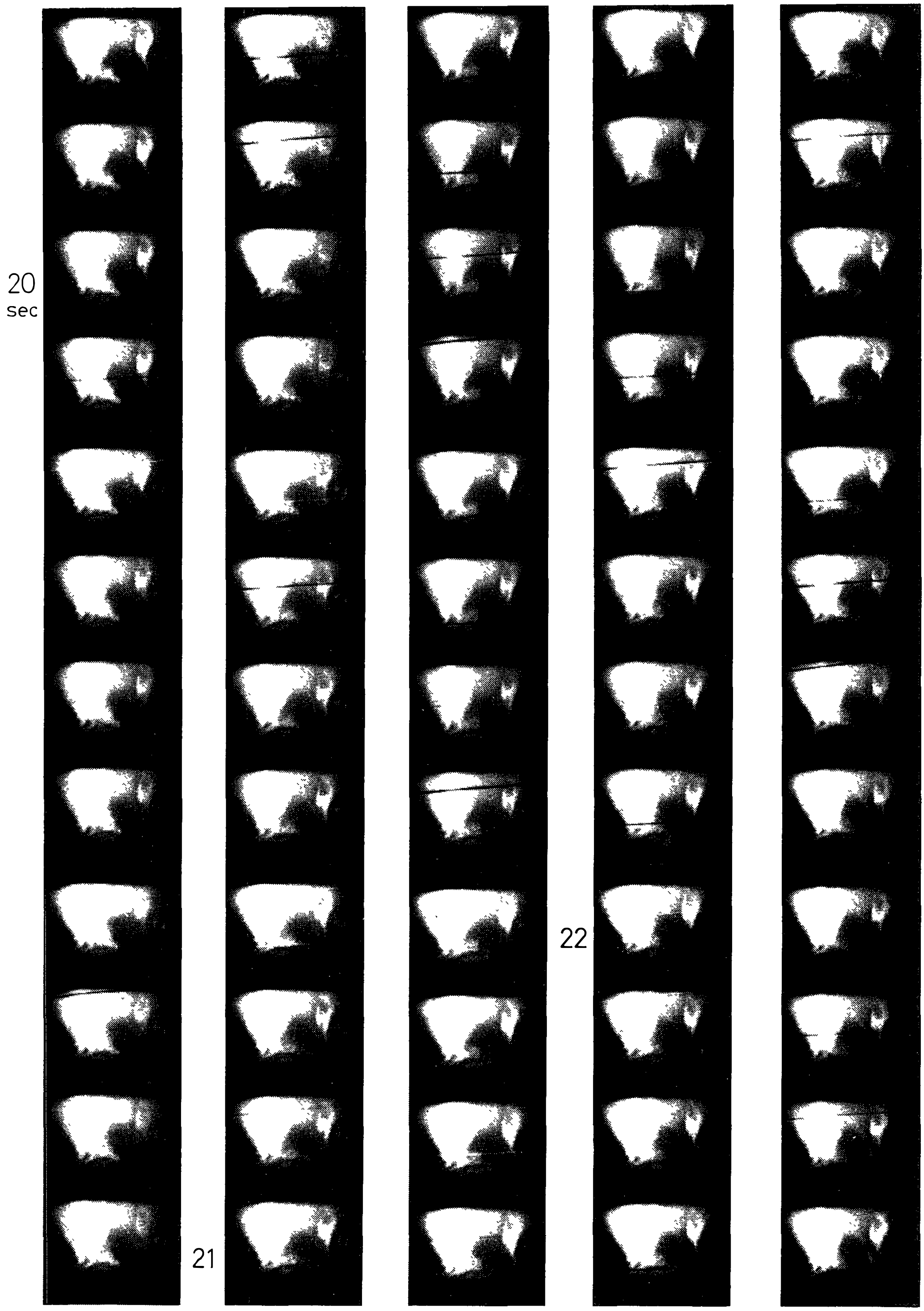


Fig. 39–2

↘*appearance of flaming-up. The pattern resembles a blaze, and it oscillates as if it were a real flame. Magnetic west, near horizon. Top is to the magnetic east, right is to the magnetic north.*

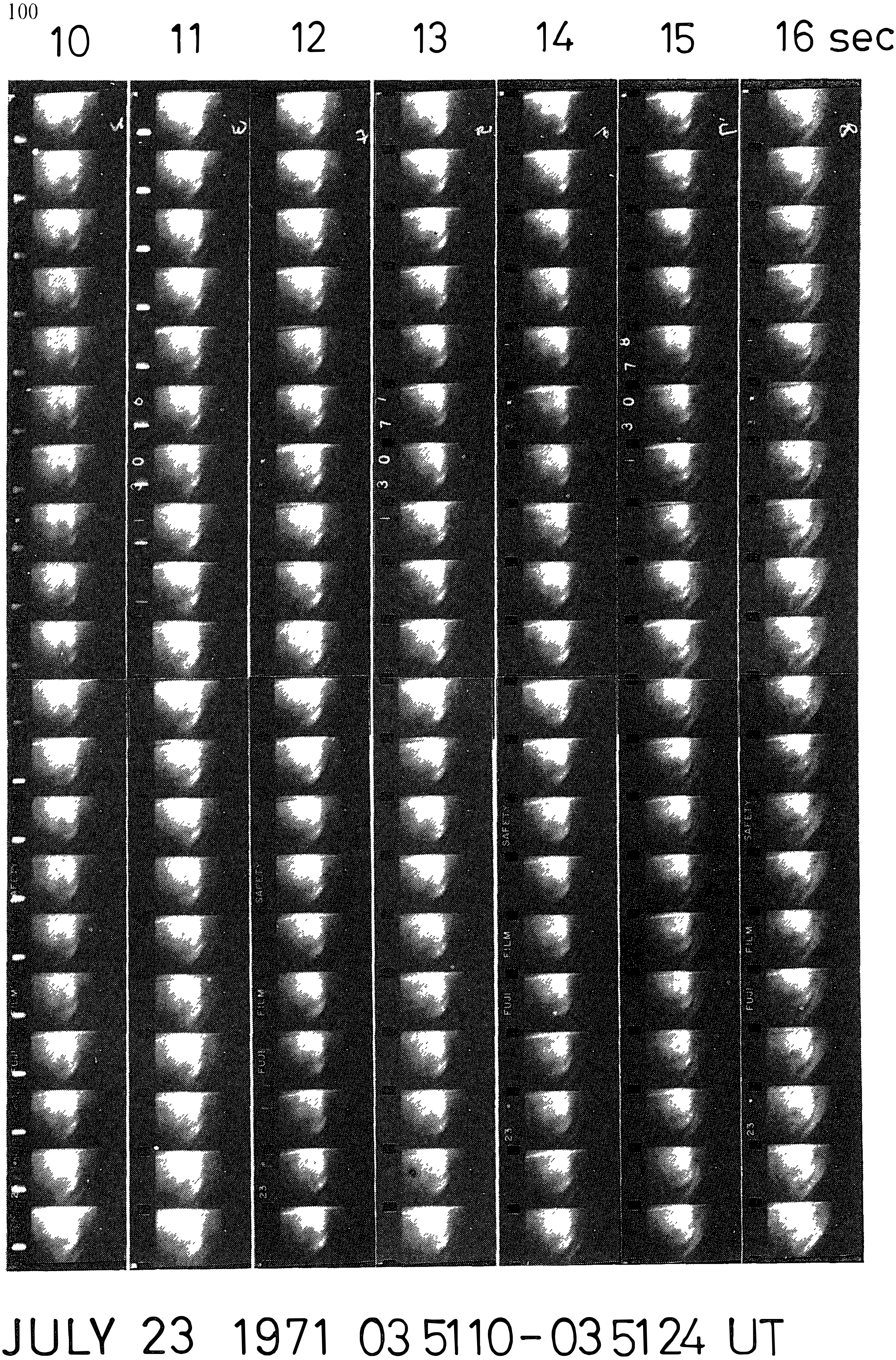


Fig. 40–1

Fig. 40. Diffuse patch auroras in the dawn almost always switch on and off very rapidly after an auroral

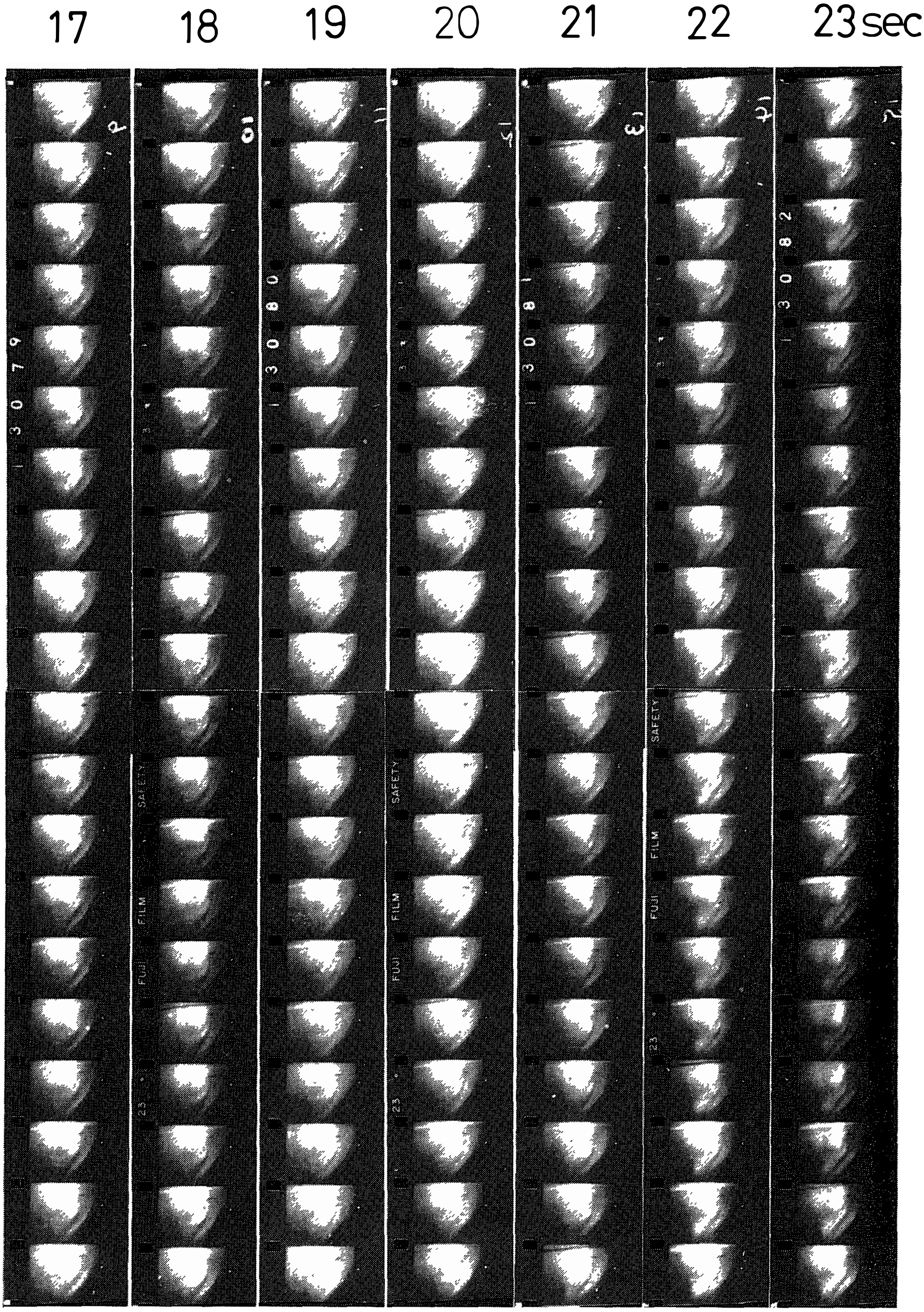


Fig. 40–2

expansion. The switching is very closely related to the occurrence of VLF chorus group emissions. Magnetic west near zenith. The top is to the magnetic east and right is to the magnetic north.