All-Sky Camera Auroral Research during the Third Geophysical Year 1957—58

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Abstract

A new type of auroral camera covering the whole sky is developed. Continuously running cameras of this type will be installed in Northern Scandinavia during the Geophysical Year in order to get a complete view of all aurorae occurring over this area. The film material obtained will be analyzed to give height and position of the auroral displays.

1. Introduction

During the Third Geophysical Year 1957—58 (AGI), a strong effort will be made to enlarge our knowledge of the physical properties of the aurorae. According to the recommendations of CSAGI[1], studies of the ionosphere, the earth's magnetism, cosmic rays and solar activity will be greatly extended during the AGI, and a network of expeditions will be placed in and near the polar regions. A great part of these have auroral research on their programmes.

The aurorae are greatly influencing ionospheric conditions at high latitudes, and radio communication through the auroral zones is considerably dependent on the presence of aurorae. This is one of the actual problems, and there is hope that the collected material from the AGI will shed light upon the whole mechanism from the disturbance on the sun to the appearance of aurorae and the resulting ionosphere disturbances, furthermore to a more exact determination of the central lines of the auroral zones and the distribution of aurora around these. Strong earth-magnetic activity results in a shift of the aurorae to lower latitudes and there is also a tendency of displacement of the auroral zones depending on season and time of day.

Visual observations and sporadic photography of aurorae are not sufficient for the study of these problems. The photographic work with ordinary narrow-angle cameras, however, has great importance when studying aurorae on a smaller part of the sky.

During the last 50 years, the different auroral forms have been analyzed by this photographic work and height and position determinations based upon thousands of photographs have been made. Despite the highly developed methods, there has been need for a network of all-sky cameras which gives a continuous survey of an aurora season also including periods without visible aurorae. In order to arrive at a practical realization of such a project which is expedient with regard to the costs of film, personnel and evaluation of the records, a compromise must be made, resulting in a limitation of film size and the number of exposures per minute.

[1] Commission Scientifique de l'Année Géophysique Internationale.

Assuming a mean of 12 hours' running each day during September—April and using a chain of six cameras constructed for 16 mm film and one exposure per minute, the total film consumption will be 6750 meters per year. Since it is not possible to photograph each night because of poor visibility and weather conditions there may be a loss of say 25 % and a resulting consumption of about 5,000 meters a year. The total costs of film and developing will then be about Sw. cr. 8,500 a year.

It has already appeared during the film tests in March—April 1955 that sometimes it would be of advantage to extend the number of exposures up to two per minute. This would give better records of rapidly changing auroral displays. On the other hand, this change would not be enough reason to double the total film costs.

2. Some Problems in Auroral Research

The aurora is a physical phenomenon which mainly occurs in the lower part of the ionosphere. The minimum and maximum heights of observed aurorae range between 75 and 700 km with an approximate centre of the distribution around 110 km height. About 94 % of all aurorae are observed between 90 and 130 km height.

The corpuscular theory of the aurorae has been established by Birkeland and experimentally verified by his laboratory experiments about 1905 with artificial aurorae on the *terrella*. His experiments gave an explanation of the auroral zones, lying at approximately 67° magnetic latitude, and their displacement to lower latitudes during periods of strong earth-magnetic activity.

Great effort has been made in Norway since many years to study the location and distribution of aurorae by simultaneous photography from two or more places, the first such photographs being made by Störmer at Bossekop in 1910 using a base line of about 5 km. Later a chain of stations has been established and is still in operation in Southern Norway and at Tromsö.

By using stars on the photographs it was possible to calculate the position of the aurorae. A summary of the Norwegian observational methods is given by Harang (1951).

Different theories have been tried for explaining what is happening in the interval between the approach of the corpuscular stream from the sun to the earth and the appearance of a luminous aurora.

There is no discrepancy that the primary source of the aurorae is a radiation from disturbance centres on the sun's surface. There is a marked correlation between sunspot periods, aurorae and periodical variations of the earth's magnetic field. The general view is that the charged particles follow the lines of force of the earth-magnetic field towards the polar regions thus producing aurorae. There is still controversy on what is happening in space at a distance of a few earth-radii from the earth's equator.

The form and position in space of aurorae give some necessary information for the study of the charged particles which produce aurorae. An all-sky camera is doubtless an ideal tool for the study of auroral forms and their changes. The small picture-size and the 180° angle reproduced on the picture may cause small details such as ray structures to be lost, but the great advantage of the camera lies in that the aurorae are photographed over the whole sky. A network of about four all-sky cameras in Northern Sweden will give sufficient accuracy for a determination of the position in space of the aurorae.

3. Aurorae and Ionospheric Conditions

One of the aims of ionosphere research is to get a world-wide survey of ionospheric conditions and a more complete understanding of the influence on the ionosphere from solar disturbances and enhanced geomagnetic activity. The aurorae are an indication that a disturbance on the sun has appeared and the aurorae are changing the structure of the ionosphere in such a way that severe interference on radio communication through the auroral zones will be present. The F1 and F2 layers commonly show a decrease in critical frequencies and an increase in height, and ionospheric records taken during such disturbances show that the lower border of the ionosphere, the D-region, is blanketing the layers above by *high absorption of radio waves*, and the loss of echoes will often be total on all frequencies. Sporadic layers of high ionization often appear in the E-region at high latitudes during aurorae. These correlations were systematically studied already during the Second Polar Year 1932—33.

In figure 1 an illustration is given of the different disturbances caused by the solar flare on October 14, 1953, and what part the aurorae play in this connection.

Immediately after the flare, the ionosphere at Upsala showed a direct effect due to the intense ultra-violet radiation from the sun. The absorption was very high (high $f_{\text{min.}}$-value). No aurora occurred this day and the sky was clear. On October 15 the corpuscular stream had reached the earth giving raise to a strong auroral display with arcs, rays, draperies and corona. The following disturbances were simultaneously noted:

1. Strong aurorae observed at Malmberget, lat. 67.3° N, long. 20.6° E.
2. Enhanced geomagnetic activity. K_p = geomagnetic planetary index.
3. Poor radio propagation conditions; the CRPL Q-values indicate radio propagation conditions in the North Atlantic area. The vertical lines represent the approximate upper and lower limit of the frequency band in Mc/s on which radio stations are received at Upsala.
4. Decrease of critical frequencies of the F-layer at Upsala and pronounced ionospheric storm tendency.
5. Improved reception of a long wave station (Warsaw, 227 kc/s) due to the high D-region ionization.

Upsala Ionosphere Observatory makes continuous ionosphere records at Upsala since 1952. In the near future two ionosphere recorders of panoramic type, taking rapid film records synchronously with the all-sky camera, will temporarily be installed at about 64° latitude in North Sweden, near Lycksele. The combination of rapid ionosphere records and the planned network of auroral cameras during the AGI will give possibilities for the detailed study of the ionosphere during aurorae. The recorders are of new construction with an extended frequency range down to 0.3 Mc/s and are accordingly suited for observation of the lower part of the ionosphere.

The map in figure 2 shows the approximate location of the Northern auroral zone and the positions of ionosphere recorders and aurora cameras during the AGI.

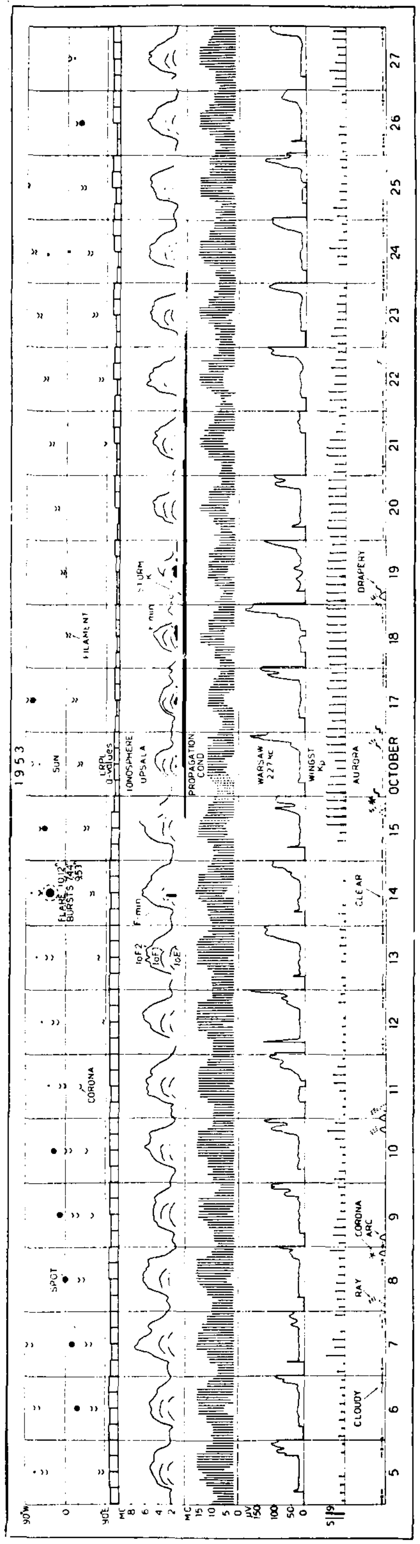

Fig. 1. An example of enhanced auroral activity and other geophysical disturbances caused by the solar flare on October 14, 1953.

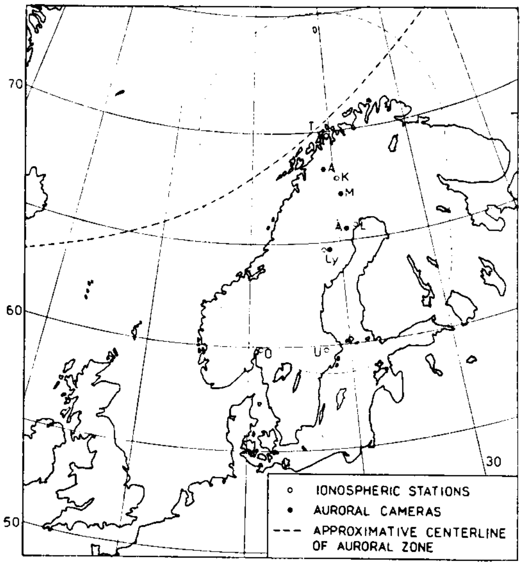

Fig. 2. Map showing the net of ionosphere stations and aurora cameras in Scandinavia during the AGI.

Ionosphere recorders:

T = Tromsö, Tromsö Auroral Observatory
O = Oslo, Ionosphere Station Kjeller, Norwegian Defence Research Establishment.
K = Kiruna, Chalmers University of Technology, Gothenburg.
L = Luleå, Royal Board of Swedish Telegraphs, Stockholm.
Ly = Lycksele, Upsala Ionosphere Observatory.
U = Upsala, Upsala Ionosphere Observatory.

All-sky cameras:

T = Tromsö, Upsala Ionosphere Observatory
A = Abisko, Upsala Ionosphere Observatory
M = Malmberget, Upsala Ionosphere Observatory
Ä = Älvsbyn (Luleå) Upsala Ionosphere Observatory
Ly = Lycksele, Upsala Ionosphere Observatory.

The places for the all-sky cameras have been chosen because of the possibilities of getting assistance from already existing institutions. The dotted line around the observational network indicates the approximate area covered by the auroral cameras. As a reasonable limit aurorae lower than 10° declination are not taken into account. Otherwise the range will be much more extended.

Radio reflections on very short wave-lengths have been obtained during aurorae since 1940 and this technique has been developed after the war by making use of radar equipment with some modifications. There is still discussion between different workers in this field whether the echoes are direct reflections or backscatter after reflection at an intense sporadic E-layer formed along the auroral zone. For the study of this an all-sky camera must be of great value for comparison of the distances measured by radar and the photographic observations.

4. Visual Observations

During 1953 a visual observational method was tried using prepaid postcards for reporting (figure 3).

A number of about 20 observers in Middle and North Sweden made regular observations. In this way the time, approximate direction, approximate height, type and brightness of the aurorae were reported. A summary of the observations showed that this method had some value for a coarse survey of the auroral activity. An experience was also gained of the difficulties of this method.

It is a great problem to find a staff of observers with sufficiently identical manner of reporting observations and it is further difficult to obtain observations without interruptions.

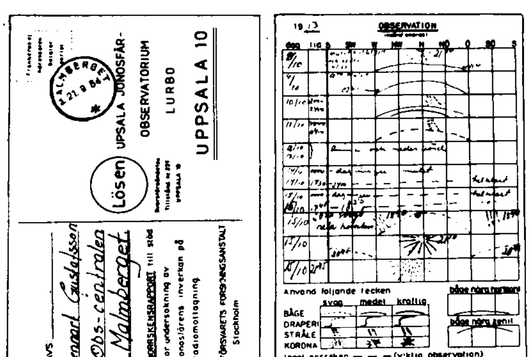

Fig. 3. Sample of aurora report on special cards.

The method can only be based on observations at fixed times or the cost will be prohibitive.

The accuracy of the visual observations by only looking at the sky is not great enough. A typical mistake is reporting the aurorae at much higher angles than they really are. From these reasons it was decided in the same year to use all-sky cameras instead of visual observations in North Sweden. The visual observations will continue, however, and will be a supplement to the photographic methods. Since it is too expensive to arrange photographic observations from South Sweden, visual observations from this part of the country will be of great supplementary value. Instructions for the observations will be given and simple mechanical means for a better determination of the position in the sky of aurorae are recommended. It is hoped that a great number of observers from schools and institutions will participate in this way during the AGI.

5. The All-Sky Camera

The requirements of the camera are as follows:

Great light power of the optical system in order to get short-time exposures.

An aperture of 180 degrees.

The best possible resolution despite the wide-angle coverage.

Avoiding of complicated optical arrangements.

Possibility of using a commercially manufactured 16 mm camera or parts of it.

A construction which is easy to handle and suited for the climate at high latitudes.

Synchronous exposures of all cameras in action.

A camera has been developed for meeting above demands with reasonable costs. Figure 4 shows the complete arrangement consisting of a hut, 2 × 2 meters with a hinged roof which is easy to let down. The camera is mounted on a heavy stand and two crossed arcs with small light bulbs built in for every 10th degree elevation angle are arranged to give a coordinate system for facilitating the evaluation of the films.

An ordinary objective Switar 1 : 1.4 is used. The spherical mirror is aluminized on the outside and provided with a hole in the centre great enough to pass the image to the camera placed below. The plane mirror on the top of the camera is of 110 mm diameter and the camera photographs the sky up to 78° elevation. By this arrangement only a small part of the sky is lost, contrary to some earlier systems which have the camera in the place of this plane mirror. Both mirrors are electrically heated, controlled by a thermostat. The camera is driven by a synchronous motor for 50 c/s and it will be easy to run several cameras synchronously at places which have the same mains frequency—this is the case in almost whole Sweden. Special arrangements will be made at those places not connected to the same net, as Tromsö and Abisko, The start of the cameras is made at an agreed time using chronometers. In this way the cameras will be running the whole night with synchronous exposures. The new cameras now under construction will be furnished with a clock, which is photographed on each picture. All films will also be marked with date and initials giving the place of observation.

Fig. 4. The complete camera arrangement opened for observation. Figures 5 a, b show the arrangement of the mirrors and figure 6 shows the optical details.

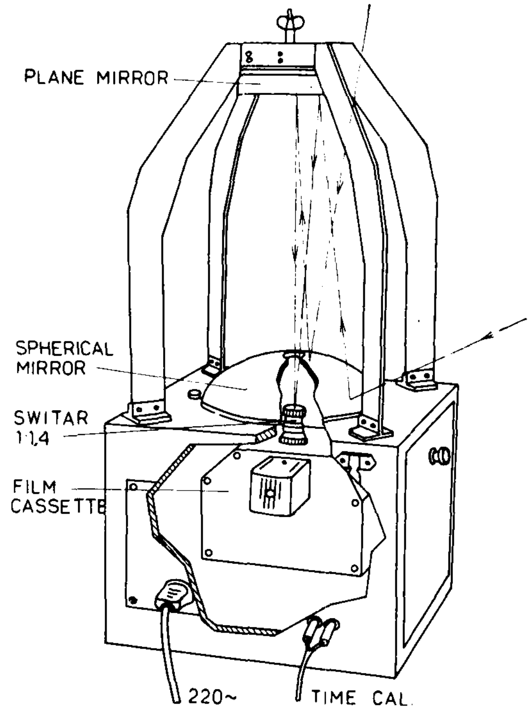

Fig. 5 a. The camera mounted on its stand.
b. The optical principle of the camera.

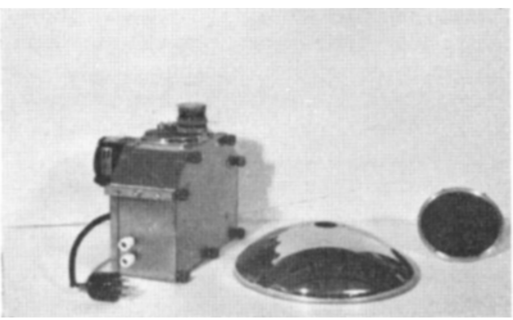

Fig. 6. The optical system of the camera.

6. The optical properties of the camera

During the construction of the camera two principal optical problems had to be solved. The first was to get a nearly linear reproduction of the whole sky and the second to get sufficient resolution despite the small picture size. The mirrors were constructed using a graphical method; the radius and diameter of the spherical mirror were found in this way. The mirror received from the manufacturer had some minor deviations from the calculated dimensions, but nevertheless the linearity is good as seen in figure 7 below.

After some experiments the different dimensions of the optical system were fixed and a calculation of the optical properties was made by A. Bring. The camera reproduces a virtual picture situated on a plane at a certain distance from the objective. The problem is whether the picture is deformed on this plane. The calculation shows, however, that this deformation is not severe and it further shows that the optical resolution on the film surface is about 100 lines per mm, which is of the same magnitude as the resolution of the film emulsion used. Several stars have been identified on the films and this is a good test on the resolution.

Figure 7 shows a picture with a very interesting auroral display.

The lamps are seen clearly and the black lines in NE, NW, SE, and SW are markings

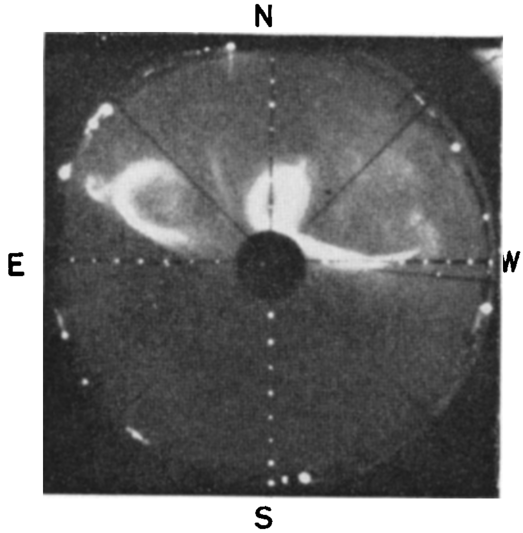

Fig. 7. An aurora of unusual type.

from the supports for the plane mirror. The picture clearly shows the efficiency of this type of photography.

The Western part of this aurora is situated over the Norwegian coast, near Lofoten, and the Eastern part is over Northern Russia, southeast of Kirkenes. This picture is subject for special studies. According to the theory (ALFVÉN, 1950), this trochoidal aurora form may be developed in either an inhomogeneous field or a combination of an homogeneous magnetic field and an electric field. The trochoid is in such a case the result of a circular motion with a superimposed drift motion.

The details of the picture are such that three stars can be detected. One of these can be seen near the antenna mast in the Western direction.

The film strip in figure 8 contains nearly all principal forms of aurorae. Pictures 1—5 show some phases in the development of the auroral form in figure 7. The ray structure is clearly visible in picture 4. Pictures 6—9 show arcs and draperies. Picture 11 resembles a bright flame from zenith to the northern horizon. Pictures 14—18 show different phases of a corona.

These film strips are a good example of the change appearing between each picture when using one exposure per minute. All these pictures were taken with 7 seconds time of exposure, this time being most suitable for this camera and the film used (Gevapan 32°). There is no intention of varying the exposure time depending on auroral brightness. A time of 7 seconds secures that even weak aurorae are photographed, and there is no severe danger of over-exposure. A fixed time of exposure makes it easier to classify the aurorae according to their brightness.

7. The interpretation of the aurora films

The great number of aurora films from the winter 1957—58 will make special arrangements necessary for the interpretation of this material. Moreover, the aurora cameras will also, to some extent, be running during other years. As mentioned before a chain of cameras will be installed at such distances from each other (120—150 km) that it will be possible to find the height and position of recorded aurorae by easy means. Different ways may be tried to find the most effective method of interpretation and at present an arrangement according to the following is under construction. A film projector will be built with 6 identical optical systems. Using this projector 6 pictures of 6 × 6 cm size, representing simultaneous records from the 6 stations in operation, will be projected side by side on a measuring table. The 6 projector units can be coupled together and each picture of the films may be studied without further synchronization. Each series of 6 pictures can be copied if wanted.

The primary result of one picture series will consist of a table containing time of exposure, elevation and bearing for a number of chosen points of the aurora for each observing station. This table will then be used for a determination of the position of the aurora by means of a mechanical device according to figure 9.

A horizontal rotating disk with an azimuth dial is mounted at the place of each observing station on a large curved map. Each of these disks supports a vertical dial with a steel pointer, which can be put in any direction between 0°—90°. After adjusting each of the 6 pointers to directions given by corresponding film pictures, the point of intersection of the pointers will give the geographical position and height over the earth surface of the chosen point of the aurora considered. These

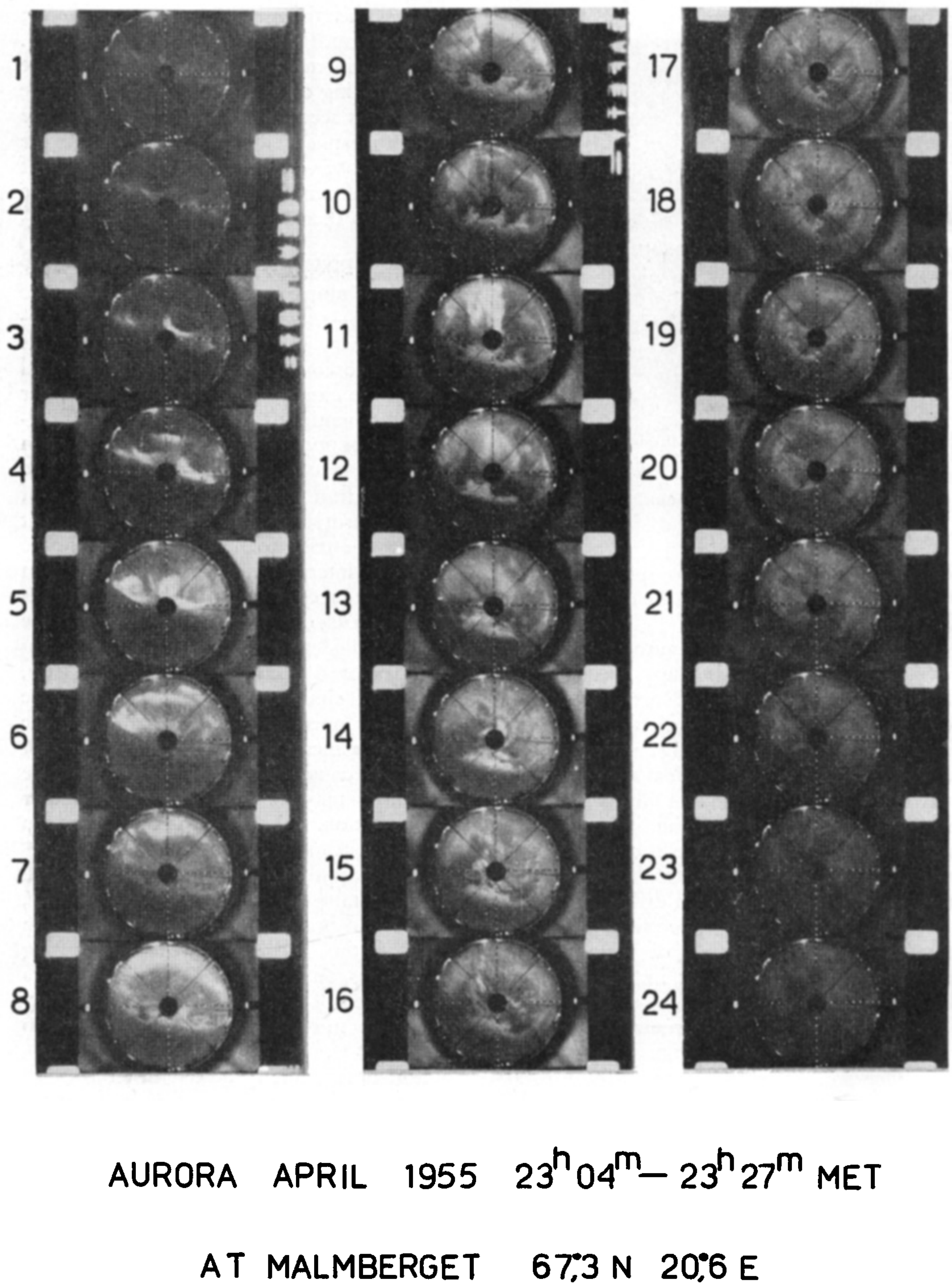

Fig. 8. Film strip of an aurora.

data will be put into a final map. The final result of the aurora films taken during the AGI will be brought together in a catalogue containing a survey of all aurorae observed and maps of their positions together with typical pictures. For statistical studies a great number of aurora observations may be brought together in three-dimensional models. The method of evaluation indicated above does not require personnel of high training.

This special projector arrangement is even usable for the study of the ionospheric records made at the same time.

Acknowledgement

I am much indebted to Mr A. Bring for his mathematical treatment of the optical system and to Mr H. Derblom for his assistance during the construction of the camera and the tests in Northern Sweden.

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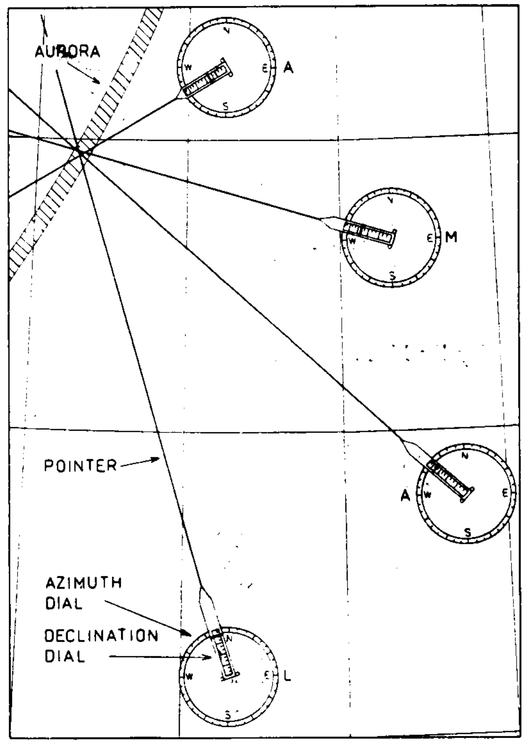

Fig. 9. Principle for determination of the position of aurorae.