Contents.

HEIGHT MEASUREMENTS OF SELECTED AURORAL FORMS

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§ 1. Introduction.

From the great material of parallactic photos of aurorae photographed and reduced according to methods first developed by Størmer from the first successful observations in 1911 up to recent years, an extensive statistic survey of the frequency of the auroral heights has been given.[1] In his latest paper Størmer has made a closer study of the appearance of special auroral types, their occurrence and developments; we would in this connection especially mention the study of the action on sunlight of the heights of the aurorae.[2]

Of recent years a great material of parallactic photos of aurorae amounting to several thousands has been collected at the Auroral Observatory in Tromsø. The working up of this material will be both laborious and expensive, and it may be doubted whether a detailed reduction of the photos collected and still being regularly collected, is worth the amount of labour involved. By experience one may, by inspecting the negatives and consulting the diary, get an impression of which a series of pictures will be of special interest. A discussion of a number of series of parallactic photos selected from a great material is given below. In all cases we have used series of photos taken in rapid succession of the same auroral form. The point of view has been to give a discussion of the appearance of the more unusual auroral forms, to study the action of the sunlight on the distribution of heights, and, by spectrograms, to study the spectral variations within the auroral forms.

An outline of the methods used for reduction will be given below, a more detailed description being given in the papers to which reference is made.

Regarding the presentation of the results, this is given in a more condensed form than usual as tables containing the results of the single determinations have. to a great extent, been omitted and the results given in figures.

The positions given in the figures are based on 286 pairs of photos. The complete number of pairs which have been calculated and of which the material in this paper is a selection, amounts to more than 700 pairs.

§ 2. Methods of photography and reduction.

The methods are the same which have previously been used at the observatory and described in detail by Tønsberg and the author.[3] The simultaneous photography at the observatory and at the second auroral station at Tenness was conducted by telephone. The two auroral cameras were of the Krogness-Størmer pattern and furnished with Astro *R-K* objectives, the light power was $f = 1:1.25$ and the focal length $F = 50$ mm. The Sonja *E-W* plates which have a high speed in ultra violet, were used for the greater part of the parallactic photography. In some cases when photographing the faint sunlit auroral arces and bands

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1 C. Størmer: Bericht über eine Expedition nach Bossekop zwecks photographischer Aufnahmen und Höhenmessungen von Nordlichtern, Vid.-Selsk. Skr. 1911, Oslo. Rapport sur une expédition d'aurores boréales à Bossekop et Store Korsnes pendant le printemps de l'année 1913, Geof. Publ. Vol. l, No. 5, 1921, Oslo.

Vegard and Krogness: The Position in Space of the Aurora Polaris from Observations made at the Haldde Observatory 1913—1914, Geof. Publ. Vol. I, No. 1, 1920, Oslo.

Harang and Tønsberg: Investigations of the Aurora Borealis at Nordlysobservatoriet, Tromsø 1929—1930, Geof. Publ. Vol. IX, No. 5, 1932, Oslo.

2 Nature, *123*, 82 and 868, 1929. ZS. Geophysik, *5*, 177, 1929. Geof. Publ. Vol. XI, No. 5, 1935, Oslo.

3 Loc. cit. p. 4—11.

appearing on the luminous afternoon sky, we used the strong orthocromatic plates Agfa Isochrom in order to reduce the effect of the strong violet radiation from the afternoon sky.

The negatives were projected through lanterns on a white sheet of paper, the enlargement corresponding to one degree being equal to one cm on the paper. The outlines of the aurorae were drawn up and the stars marked off. The two drawings, A and B, prepared from the simultaneous pictures taken at Tromsø (A) and Tenness (B) were placed on a glass plate and illuminated from below. The two drawings were adjusted so that the stars covered each other and the outlines of the B-drawing were drawn up on the A-drawing. In the further reduction work "nets" and "artifical stars" were used, the principle of application will be mentioned below.

For the sake of the completeness we give the system of formulas to be used for reduction.

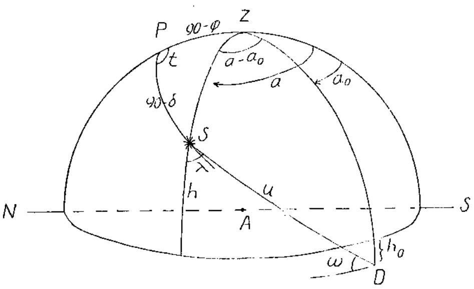

Fig. 1.

Let us consider the sky from the principal station A. The base-line A—B cuts the celestial sphere at the point D in the direction A to B. This point we shall call the *base-pole*. Let S be a star. The plane ADS we call the *plane of displacement*, because an auroral point lying in the direction AS will be displaced in this direction when viewed from the station B. The celestial point S may now be determined by *three* systems of spherical coordinates referred respectively to the pole (P), the zenith (Z) and the base-pole (D), and the corresponding coordinates will be (t, δ), (a, h) and (ω, u), — the latter we shall call the *base-altitude* and the *base distance*.

Usually, we have the celestial points, for instance, given by δ and t. We then compute the corresponding spherical coordinates in the two other systems by the following equations.

$$\sin h = \sin\varphi \sin\delta + \cos\varphi\cos\delta\cos t$$
$$\sin a = \cos\delta\sin t \sec h$$
$$\cos a = -\cos\varphi\sin\delta\sec h + \sin\varphi\cos\delta\cos t\sec h$$
$$\cos u = \sin h_0 \sin h + \cos h_0 \cos h \cos(a - a_0)$$
$$\cos\omega = \cos h \sin\lambda \sec h_0$$
$$\operatorname{cotg}\lambda = -\operatorname{tg} h_0 \cos h \operatorname{cosec}(a - a_0) + \sin h \operatorname{cotg}(a - a_0).$$

In these equations the letters signify:

φ the geographical latitude of the principal station
δ » declination of the star
t » hour angle
h » height
a » azimuth
u » base-distance
ω » base-height
λ » angle between the plane of displacement and the vertical plane
h_0 » height of the base-pole
a_0 » azimuth of the base-pole.

The transformation of coordinates from one system to another of the three spherical systems mentioned above, is highly facilitated by means of "nets" and "artificial stars" previously introduced in the methods of reduction. Concerning the construction and application of these, we refer to the earlier publication;[1] we would only mention that by means of these one avoids the laborious computations of (a, h) and (ω, u) for a celestial point using the formulas given, the coordinates being taken out by the "nets" and the "artificial stars". Further, one may along an auroral contour select an arbitrary number of points and easily get their coordinates (a, h) and (ω, u) read off on the drawings directly.

For a point on the auroral contour it is easily shown that the distance r_1 from the principal station A to the point is given by the equation

$$r_1 = \frac{g \sin u_2}{\sin(u_2 - u_1)} = g \sin u_2 \operatorname{cosec}(u_2 - u_1)$$

where u_1 and u_2 are the base-distances of the corresponding points on the Tromsø- and Tenness-contour respectively, ($u_2 - u_1$) is the parallactic angle p and g is the length of the base in km.

The height H of an auroral point above the surface of the earth can be determined when knowing the distance r_1 from the principal station and the elevation h, and is here determined by graphs explained in the papers mentioned. Determined in the same way is the distance D along the earth's surface

[1] loc. cit. p. 4—11.

from the principal station to the horizontal projection of the auroral point on the earth's surface.

The geographical coordinates of the two stations were as follows:

Tromsø: $= 69°\,39'.8$ N, $= 18°\,56'.9$ E. Gr.
Tenness: $= 69°\,18'.0$ $= 19°\,20'.54$.

The heights above sea-level are 112 m and 12 m respectively. Using these values, we get the following values for the base-line and the base-pole D:

$$g = 43.4 \text{ km}, \quad h_0 = -0°.33, \quad a_0 = -20°.96.$$

In a number of cases the position of the shadow-line dividing the sunlit part of the atmosphere from the part lying in the shadow is demonstrated relative to the position of the aurorae. The computation of the height of the earth's shadow was performed in the following way. The horizontal projections of the auroral points were marked off on a map from a series of pictures. The series of auroral pictures had usually been taken in the course of 2—3 minutes and one can therefore with sufficient accuracy use the mean time during the photography in the computations. Usually, the auroral points calculated represent the lower border of arcs, bands or draperies, and, along the horizontal projections of the aurorae one selects a number of points, usually three, and computes the height of the shadow line above these points.

The angular height of the sun is determined by the following equation:

$$\sin h = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos t$$

where δ is the sun's declination and (φ, t) is the geographic latitude and the sun's hour angle at each of the points selected. To this height h, being negative for points in shadow, one has to add the double amount of the atmospheric refraction, to be valued to $1°.10$. The elevation X of the shadow-line above the points selected is determined by

$$X = R\,(\sec h - 1)$$

where R is the mean radius of the curvature of the earth's surface, 6 395 km in our territory of observation.

On the diagrams we usually mark off the position of two shadow-lines, the upper broken line is computed without taking the effect of refraction into account, for the lower one, the effect of the atmospheric refraction has been considered. In the figures we have usually drawn the earth's surface as plane, further, a different scale in horizontal and vertical directions is used, the latter being double the former, in order to demonstrate the height variations of the aurorae more distinctly. This involves that the shadow-lines in the figures not will be straight lines.

§ 3 a. 24. 11. 1930. Auroral ray extending to a height of more than 300 km and lying in the shadow.

From the descriptions of aurorae lying in the sunlit and dark atmosphere, which will be given in the last part of this paper, one has the impression that in the region of the auroral zone the upper limit of rays and draperies lying in the *dark* atmosphere very seldom attain heights up to 300 km.

In the report of Vegard and Krogness [1] on the height measurements from the Haldde Observatory, only one auroral point having a greater height than 300 km is mentioned (measured with a base-line of 12.5 km) and in Størmer's report on the results of his expedition to Bossekop in 1913 [2] only two auroral points having a greater height than 300 km are mentioned (measured with a base-line of 27.5 km). In the height measurements from the Auroral Observatory from 1929 and the Spring of 1930 [3] we only in one case measured an auroral ray where the upper limit attained a greater height than 300 km. In Størmer's later papers [4] the great heights attained by sunlit aurorae in the southern part of Norway were discovered.

A single ray showing a visible luminosity from 300 km down to 100 km in the *dark* atmosphere is in fact very rare, and the appearance of such rays must be associated with special circumstances either concerning the velocity and orbits of the electrically charged particles producing the aurorae, or the physical state of the atmosphere at heights of 100—300 km.

In this connection we would mention an auroral ray photographed on 24. 11. 1930 at $22^h\,52^m\,39^s$ MET. The height of the upper limit was 296 km, but as the ray here went out of the field of the camera, the maximum height of the upper limit was above 300 km. The lower boundary was at 109 km.

The appearance of the aurorae on this evening was very peculiar. Early in the evening single rays

[1] loc. cit. p. 73.
[2] loc. cit. p. 214.
[3] loc. cit. p. 44.
[4] Résultats des mésures photogrammétriques des aurores boréales obsérvée dans la Norvège méridionale de 1911 à 1922. Geof. Publ. Vol. IV, No. 7, 1926, Oslo.

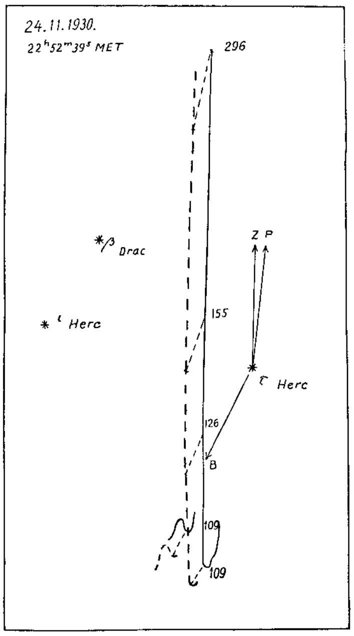

Fig. 2.

appeared and disappeared as lightning strokes in the sky; they changed so rapidly that it was impossible to obtain photos of them with the auroral cameras on account of the rapid movements. The streamers were occasionally red-coloured or bordered with a deep green-coloured edge. Later in the evening more quiet forms appeared and some parallactic photos of rays and draperies were taken.

On the two following evenings very intense but more quiet forms of ordinary arcs, bands, and draperies appeared, and a number of photos of these more usual forms were taken. These three evenings show a gradual change of the character of the auroral displays during a great "auroral period" which have experienced in a number of cases. On the first evening the rapidly moving forms as draperies and rays predominate, usually without too great intensities. On the following evenings more quiet but much more luminous forms appear, until the great period of activity die out after some days.

It is interesting to note that the astonomers on the 25. 11. observed by means of the spectrohelioscope a quite unusual solar activity. In a note in "Nature" (*126*, 969, 1930) from the Solar Observatory Greenwich it was reported that eruptive prominences possessing velocities outwards of more than 100 km/sec and up to 400 km/sec were observed in hydrogen light. The sun spots were not of an unusual great size, but the hydrogen prominences showed quite unusual velocities and extensions.

§ 3 b. 28. 10. 1932. Height measurements of "auroral clouds".

One of the most puzzling auroral types is the cloud resembling aurorae which often occurs late in the evening after very intense auroral displays. The colour of these forms, is more grey-white than the usual yellow-green aurorae. Often one observes rhythmical changes of the light intensity. We have in some cases observed periods of less than a second, but usually the period of pulsation is longer, say half a minute. Height measurements[1] show that the "auroral clouds" lie at the usual height of aurorae, 95—110 km.

The gradual formation of these cloud-resembling auroral forms during an evening may be followed by means of filter-photography in green (5577 Å) and violet (the blue and violet Nitrogen bands). It has been shown[2] that during an evening with strong auroral displays, the sky radiates an increasing amount of light in violet compared with the region in green, and the cloud-resembling aurorae appearing late in the night show the same spectral increase of violet compared with green.

Krogness[3] expressed the opinion that the cloud-resembling aurorae are self-illuminating "ion-clouds" which move with the atmosphere in the high strata. In a discussion of the successive displacements of the horizontal projections from parallactic photos of this formations, Krogness and Tønsberg[1] have shown that these formations drift with velocities of a magnitude of 150 m/sec. These studies are based on pictures taken in succession during a period of 3—6 minutes.

It may be doubted whether the cloud-resembling aurorae may be regarded as a sort of "ion-clouds". We would point out that the radio-echo experiments show that free electrons in any appreciable concentration (for instance day-time concentration of a magnitude of 10^5 electrons/cm^3 or the even much greater concentrations which appear during auroral displays) cannot exist at an height of 100 km for many seconds without being rapidly neutralized when the ionizing agency disappears, on account of the magnitude of the recombination coefficient at a height of 100 km.

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1 Harang and Tønsberg: Geof. Publ. IX, No. 5, p. 44, 1932, Oslo. Krogness and Tønsberg: Geof. Publ. Vol. XI, No. 8, p. 11, 1936, Oslo.

2 Harang: Filteraufnahmen von Polarlicht, Geof. Publ. Vol. X No. 8, p. 21, 1934, Oslo.

3 Short Report on Various Researches regarding Aurora Borealis and allied Phenomena. Tromsø 1928.

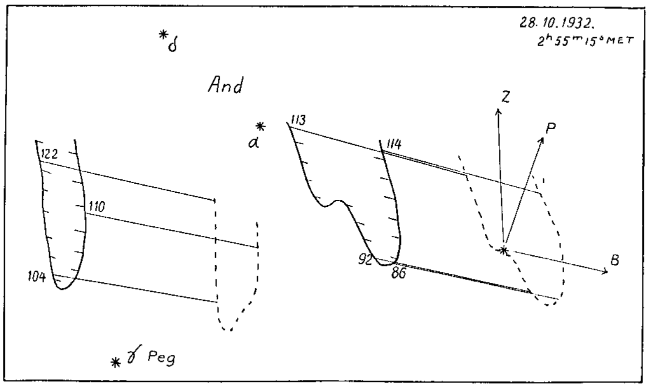

Fig. 3.

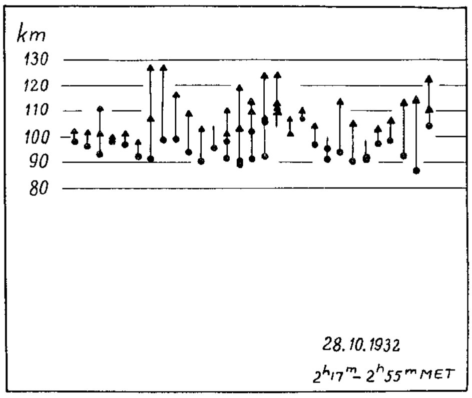

Fig. 4.

On the other hand, Kaplan's brilliant investigations on exitation of the green auroral line and the nitrogen bands in presence of active nitrogen, indicate that exited molecules with long life-time may exist in the upper strata, thus producing a kind of phosphorescence after strong auroral displays.

We give below the results of height determinations of cloud-resembling aurorae from 17 pairs of photographs taken between 2^h17 and 2^h55 MET on 28. 10. 1932.

The auroral display started early in the evening and until midnight 180 pairs of parallactic photographs had been taken. As the photographs taken only seemed to be of aurorae of the usual type, we have not calculated this material completely, and will only give the results of the height determinations of the "auroral clouds" which appeared after midnight.

Although these auroral forms seemed to be of quite the same type as previously studied by Krogness and Tønsberg[1] the photographs taken in succession of the same forms did not show any horizontal displacements in the course of 3—4 minutes. From the measurements, it is evident that the cloud-resembling forms were similar to short draperies with a lower limit at about 95 km and an upper limit at 110—120 km. In fig. 4 is given the results of the height measurements; ● indicates the lower boundary, and ▲ the upper limits.

During the observations we also succeeded in obtaining successive photographs of the pulsations. On Plate I, Nos. 2, 3, 4 and 5, four photographs taken at $2^h 51^m 33^s$, $2^h 52^m 40^s$, $2^h 53^m 57^s$ and $2^h 55^m 15^s$ MET are reproduced. In No. 4 the small cloud-like ray to the left is lacking, but on No. 5 the ray returns to exactly the same place on the photographs Nos. 2 and 3. The projections are shown in fig. 3, the parallaxes were 8°—10° and the height determinations therefore very reliable.

[1] loc. cit.

§ 3 c. 9. 2. 1934. Heights and spectra of sunlit aurorae.

The earth-magnetic records developed at 14^h on this day showed a strong perturbation during the preceding night and the storminess before noon was still considerable. We therefore made preparations for auroral spectrography and photography for sunlit aurorae which were expected to appear in the afternoon.

The first faint rays and draperies appeared in the west $16^h 50^m$, on the luminous afternoon sky. Parallactic photographs could only be taken from $17^h 34^m$, and in the time interval $17^h 34$—$18^h 36^m$ 44 pairs were taken.

Fig. 5 shows the distribution of the heights of the aurorae relative to the shadow line. In the west the upper limit of the sunlit draperies and rays attained heights up to 300 km, in the east where diffuse bands and draperies also appeared — the heights of the upper limits attained were considerably less.

Four spectra were taken on the same plate with a small glass spectrograph:

Spectrum 1: at about $17^h 10^m$ of sunlit rays and draperies in west.

» 2: at about $17^h 35^m$ of sunlit rays and draperies in west.

» 3: at about $17^h 58^m$ of yellow green aurorae in north and east lying in the shadow.

» 4: at about $18^h 08^m$ of yellow green aurorae in north and east lying in the shadow.

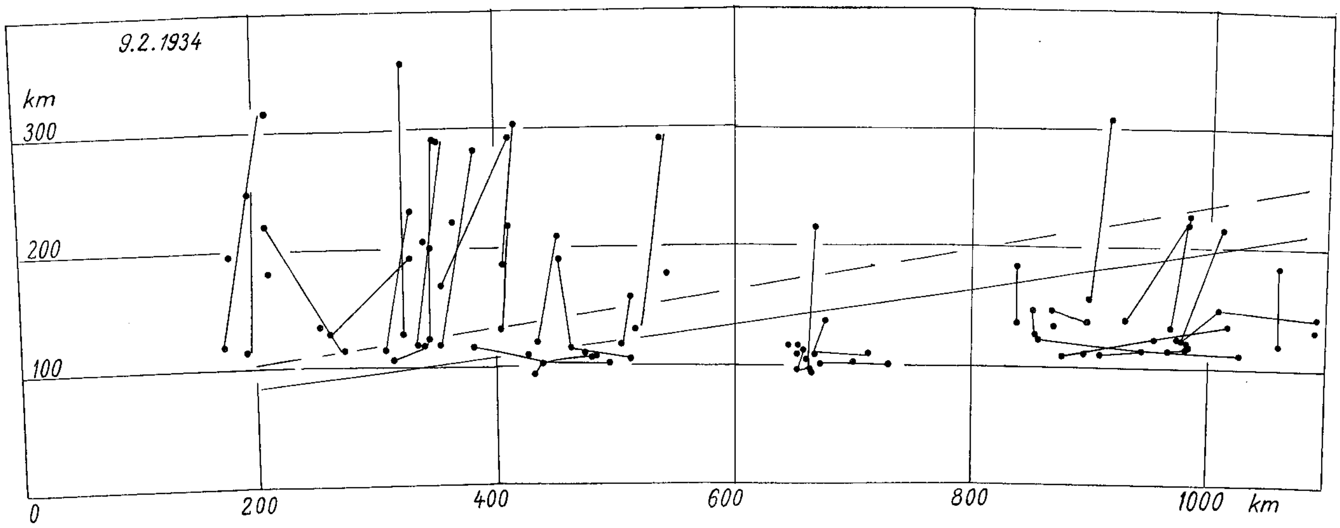

Fig. 5.

The angular height of the spectrograph during all four exposures was the same, the selective extinction is therefore the same on all spectra.

The densities of the spectra were measured out by a photo-electric microphotometer made at the observatory. Plate I No. 6 shows the spectra and fig. 6 the records. Although the slit of the spectrograph was narrow, the continuous light from the afternoon sky is strong on the two first spectra of the sunlit aurorae. From the records it is evident that on the first and second spectrum for the intensities of 5577 Å and 3914 Å we have: $^{I}5577 \leqq {}^{I}3914$, and on the two last spectra we have $^{I}5577 > {}^{I}3914$.

On a plate from the same stock, density marks by means of a Zeiss "Stufenfilter" were copied on, and developed in, the same standard developer. From this plate the intensity variation was determined quantitatively. In the following table we have put the intensity of 5577 as equal to 100 in each spectrum.

	$^{I}5577$	$^{I}3914$
Spectrum 1	100	112
» 2	100	100
» 3	100	67
» 4	100	69

The intensity variation thus confirms the observations of Størmer of the increase of the intensity of the nitrogen bands in the sunlit aurorae.

Later in the evening, between 23h and 24h 50 pairs of photographs were taken of usual green yellow aurorae. As these pictures are of the usual types, we will not give the results of the height determinations.

The earth-magnetic perturbation during the appearance of the sunlit aurorae was strong, in H a positive storm of 250—300 γ. Fig. 7 shows the earth-magnetic records during the auroral photography.

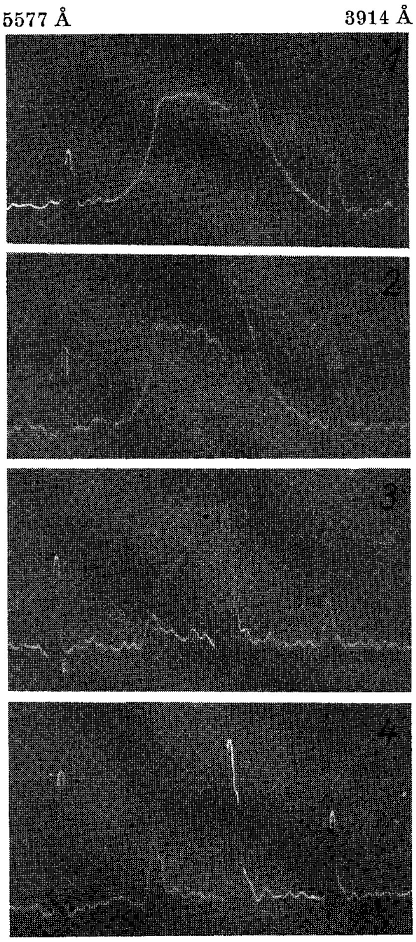

Fig. 6.

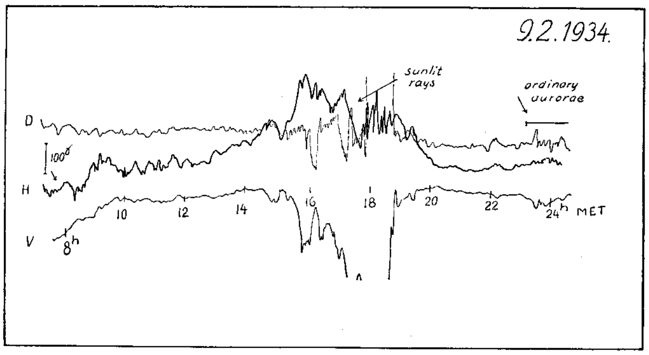

Fig. 7.

§ 3 d. 24.10.1935. Sunlit auroral rays.

At 14^h we noticed that a strong earth-magnetic storm had commenced before noon and we therefore expected brilliant aurorae during the evening. In the twilight from 16^h MET one observed very distinctly in the spectroscope the green auroral line over the whole sky, it being especially strong in the southern sky. Nevertheless, only some very feeble rays appeared in the west at 17^h50^m. Of these, three parallactic photographs were taken before they disappeared. Table 1 gives the results of the height determinations.

Table 1.

No.	MET	Time of Exposure	Constellation of Stars
1	$17^h54^m00^s$	18 sec	Corona-Bootes
2	54 36	22	» »
3	55 12	25	» »

No.	P	a	D	H	No.	P	a	D	H
		°	km	km			°	km	km
1	I1	85.8	309	205		I3	80.9	331	331
	2	84.1	302	246		4	74.3	339	506
	3	81.3	298	311					
	4	74.1	289	444		I1	86.0	374	228
	II1	72.2	352	266	3	2	84.0	378	310
	2	68.4	335	330		3	81.4	361	356
	3	62.7	308	421		4	76.0	353	475
						II1	68.3	398	283
2	I1	86.0	357	205		2	65.1	382	352
	2	83.7	328	253		3	60.7	368	454

Here *a* and *D* are the azimuth and distance along the earth's surface to the horizontal projections of the auroral points selected, and *H* is the height of the auroral point above the earth's surface. The same designations are used i following tables.

Fig. 8 a shows the position of the rays in a vertical plane relative to the earth's shadow, and fig. 8 b the position of the horizontal projections.

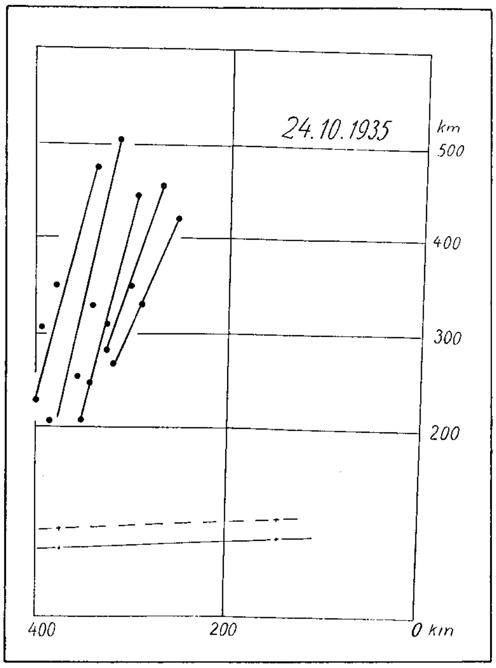

Fig. 8 a.

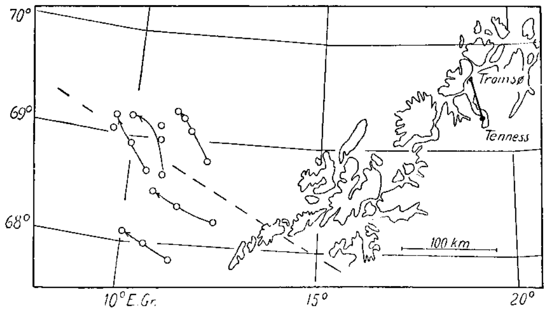

Fig. 8 b.

The dotted line in fig. 8 b indicates the position of the vertical plane represented by fig. 8 a.

The lower edge of the rays went down to 205—260 km and the greatest height the upper part of the rays attained was 506 km. The rays were completely sunlit, the shadow line reaching a height of about 40 km. The parallaxes were 4°—6° and the height determinations are therefore fairly reliable. These rays show the greatest heights attained by aurorae observed in Tromsø up to now.

From $17^h 56^m$ to $19^h 50^m$ no aurorae were visible, between $19^h 55^m$ and $21^h 46^m$ 42 pairs of photographs were taken of ordinary aurorae, draperies, bands and arcs which now appeared. As these aurorae were of the usual types, we will not give any account of the results of height determinations.

In connection with the unusual great height of the sunlit rays measured, it is interesting to make a closer study of the earth-magnetic perturbation and

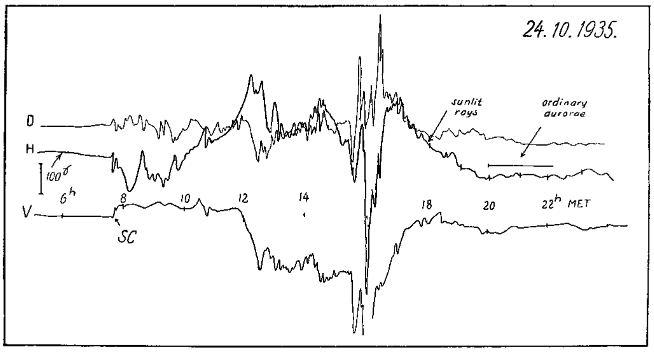

Fig. 9.

the conditions of the ionosphere derived from radio-echo measurements[1] during the auroral display.

The earth magnetic storm appeared as a sudden commencement (SC) at 7^h40^m MET. Between 13^h and 17^h the positive deflections in H were great, an increase in H of 350 γ and a decrease in V of 450 γ were attained. The high rays appeared at a moment when the deflection in H was approaching its normal value, the positive deflection being 120 γ. Later in the evening, when the ordinary aurorae appeared between 20^h and 22^h, only small, irregular deflections on the magnetogram were recorded.

In previous papers[2] the vertical movements of the atmosphere in the level of the F_2-layer have been discussed and it has been shown that the earth-magnetic storms produce an expansion of the atmosphere in layers above 200 km. It is probable that the appearance of these rays at great heights at the declining phase of the earth-magnetic storm must be regarded as an effect of the expansion of the atmosphere on account of the intense perturbation about noon.

During the perturbation at noon, the echoes disappeared.[3] In the afternoon when the auroral line was visible in the spectroscope over the whole sky, the echo registrations showed very strong E-echoes with an equivalent height of reflexion of 125 km. The sunlit rays appearing in the west seemed to have no influence on the character of these echoes. At 20^h when the ordinary aurorae appeared in zenith, complicated echo patterns were recorded showing the appearance of a number of layers in the E-level.

[1] Details of instrumental equipments and methods for observations are given in Terr. Mag., *41*, 143, (1936), Gerl. Beitr. Geophysik, *46*, 438 (1936), Geofys. Publ. Vol. XI No. 17, 1937.

[2] Terr. Mag. *41*, 143, (1936).

[3] In Geof. Publ. Vol. XI, No. 17 1937, p. 36 the results of the echo registrations during the day 23.—24. 10. 1935 are discussed.

It is interesting to compare the heights of the rays on this evening with the position of the sunlit rays and draperies photographed on the 9. 2. 1934. The sunlit aurorae on the 9. 2. 1934 were lying in an height interval of 120—300 km, whereas the rays on this evening were lying in the height interval 200—450 km. The earth-magnetic perturbation was of the same character on both days, but from fig. 5 and fig. 9 it is evident that on the first evening the height of the earth's shadow was about 100 km, and on this evening the height was about 40 km. This displacement of the auroral heights along the shadow line will be discussed in detail below in connection with the height measurements of arcs and bands lying on the border between the sunlit and dark part of the atmosphere.

§ 3 e. 27. 10. 1935. Sunlit auroral arc.[1]

Auroral rays and draperies appeared in the west on the luminous afternon sky at 16^h50^m MET. At 17^h05^m a beautiful arc with ray-structure developed from west to east extending to a height of about 80° above the horizon in north. The colour was the usual green-yellow. During 17^h12^m to 17^h18^m MET a number of parallactic photographs were taken. The western and eastern part of the arc was photographed alternately. In the west the most intense stars in Bootes (α and ε), and in the east, those in Aries (α and β) were visible. In the zenith no stars were visible and no pictures were taken as it was expected to be

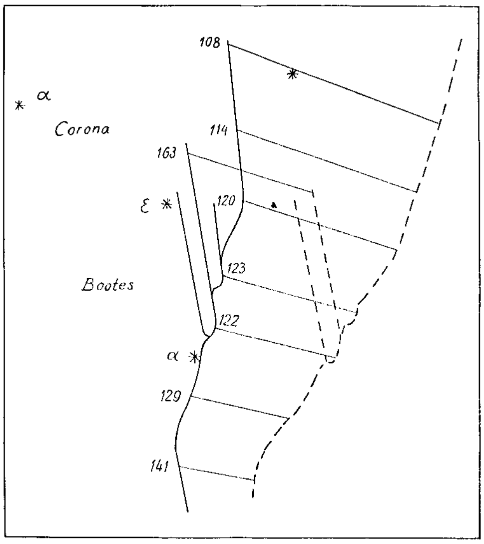

Fig. 10.

[1] A preliminary report on the height measurements of this arc has been published in Terr. Mag. *41*, 143 (1936).

Table 2.

No.	MET	Time of Exposure	Constellation of Stars	
1	$17^h12^m30^s$	18 sec	Bootes-Corona (in west)	A
2	13 15	9 »	» » »	A
3	13 28	7 »	» » »	A
4	13 37	7 »	» » »	A
5	13 58	8 »	Aries-Triangulum (in east)	A
6	14 08	7 »	» » »	A
7	14 50	6 »	» » »	A
8	15 03	6 »	Bootes-Corona (in west)	B
9	15 14	8 »	» » »	B
10	15 43	12 »	Aries-Triangulum (in east)	B
11	16 52	9 »	Bootes-Corona (in west)	B
12	17 07	11 »	» » »	B

difficult to trace out the faint stars in the strong blackening from the luminous afternoon sky.

On plate I No. 1 a pair of photographs taken at $17^h16^m52^s$ (No. 11 in tables 2 and 3) is reproduced and the projections are shown in fig. 10. The pictures were calculated twice and all determinations of the individual points are tabulated in Table 3.

The values of the parallaxes lie between 5° and 14°; the great parallaxes indicate that the possible error in the height determination of the individual points does not exceed 3 to 4 km.

The results of height determinations are illustrated in fig. 11 (A) and (B) and the horizontal projections of the auroral points are shown in fig. 12 (A) and (B).

Table 3.

No.	a	D	H
	°	km	km
1	81.9	352	140
	81.7	294	139
	81.7	237	132
	83.9	187	125
	83.6	151	119
	84.2	148	119
	86.2	117	117
	84.4	110	107
2	83.6	355	138
	83.5	348	142
	84.8	272	138
	84.2	255	124
	85.4	218	129
	85.7	198	124
	86.2	178	120
	85.6	147	117
	86.5	140	117
	88.0	121	118
	89.6	110	112
3	83.2	330	128
	84.3	276	122
	84.5	246	126
	84.9	231	121
	85.1	190	120
	85.6	169	114
	86.0	166	120
	86.3	147	113
	86.3	133	113
	87.1	113	107
4	83.3	394	135
	83.7	309	128
	84.4	266	126
	84.7	259	122
	84.6	225	123
	85.6	193	122
	85.8	188	118
	86.2	155	111
	86.4	127	108

No.	a	D	H
	°	km	km
5	180 + 74.8	432	101
	+ 75.3	430	105
	+ 75.2	307	96
	+ 74.0	280	102
	+ 72.3	232	99
	+ 71.5	204	97
	+ 71.8	174	99
	+ 71.6	165	101
	+ 71.3	148	98
	+ 71.7	144	108
6	180 + 75.4	443	96
	+ 76.2	352	108
	+ 74.7	252	100
	+ 72.4	205	98
	+ 72.1	170	99
	+ 72.3	168	97
	+ 71.0	151	101
	+ 69.3	138	105
	+ 70.7	138	102
7	180 + 77.1	312	97
	+ 77.2	300	94
	+ 79.5	252	97
	+ 79.8	230	100
	+ 80.1	212	102
	+ 81.7	169	97
	+ 81.3	162	97
	+ 77.0	114	100
8	83.0	395	125
	83.5	336	119
	83.5	294	114
	83.7	248	115
	85.0	219	115
	85.8	183	114
	85.3	165	113
	89.5	159	112
	86.6	132	110
	86.4	127	105
	88.2	107	111

No.	a	D	H
	°	km	km
9	83.9	402	130
	83.7	302	121
	83.9	248	122
	85.0	204	114
	85.7	170	115
	85.4	152	113
	87.0	135	109
	87.0	123	111
	88.9	116	111
10	180 + 83.4	300	99
	+ 83.7	285	98
	+ 84.1	254	105
	+ 85.0	238	106
	+ 84.4	196	102
	+ 85.2	186	100
	+ 83.5	162	103
	+ 84.3	152	100
	+ 83.8	135	103
	+ 83.3	130	100
	+ 83.1	118	103
	+ 82.6	104	98
	+ 82.7	103	101
11	85.0	439	141
	84.8	414	140
	85.3	323	129
	86.0	276	127
	86.3	251	122
	86.5	219	123
	86.5	195	121
	87.6	175	120
	86.3	142	114
	85.2	121	115
	85.0	113	108
	82.7*	216	163*
12	84.7	448	145
	85.0	330	130
	84.6	294	125
	85.5	239	138
	86.0	232	119
	85.2	181	118
	85.5	152	116
	85.3	140	108
	83.9	108	105

The length of the arc measured from the plates was 800 km. As the arc in the west and east went down to the horizon, the total length must be considerably greater. The position of the western part of the arc during the exposures was essentially the same whereas the eastern part was slowly moving to the south. The position of the auroral points relative to the sunlit part of the atmosphere is shown in fig. 11. Three shadow lines have been computed, *I* indicates the real shadow line taking into account the effect of the atmoshpheric refraction, *II* shows the shadow line neglecting the effect of the refraction and *III* is the shadow line indicating the part of the sun-rays which have passed above a 50 km height which represents the principal part of the ozone layer.

The main features in the distribution of the heights are that the heights of the lower border in the sunlit atmosphere are continually decreasing from the usually high value of 140 km to a value of 110 km when approaching the shadow line. The eastern part of the arc lying in the dark atmosphere has an uniform height of 100 km, which is the most frequent value for the height of the lower border of this type of aurora when observed during the night. The heights along the border are essentially the same in fig. 11 (A) and (B) which shows that the distributuon of heights was a characteristic feature of the arc which was maintained during the time.[1]

On Plate I, No. 1 and fig. 10 the ray-structure of the arc is visible. In table 3 the upper limit (*) of one ray is determined to 163 km. The height of the upper limit of this sunlit aurora is therefore of an entirely different magnitude from that of the faint gray violet coloured sunlit aurorae measured by Størmer.

Assuming the penetrating power and the geometry of the paths of the individual electrically-charged particles to be the same along the auroral arc, an assumption which by no means may be regarded as evident, the auroral heights in fig. 11 indicate the position of an isobaric surface in the atmosphere. The continual decrease of the auroral heights when approaching the shadow line makes this assumption probable and the lifting of the isobaric surface in the sunlit atmosphere may be regarded as an effect of the expansion due to the heating of the atmosphere.

If we assume that the absorbing effect of the ozone layer is negligible above 50 km we see from fig. 11 that only the auroral points lying above 120 km are exposed to the complete ionising and heating effect of the solar spectrum.

This continual increase of the heights of auroral arcs and bands when crossing the border surface from the dark to the sunlit atmosphere, will be demonstrated in a number of cases below.

Observations of radio echoes during the appearance of the sunlit arc.

During the appearance of the auroral arc the ionisation of the upper atmosphere was determined by measuring the critical frequencies by means of radio echoes. The usual effect is that aurorae and earth-magnetic of low or medium intensity are accompanied by a strong increase of the ionisation in the level of the E-layer, whereas strong magnetic storms and intense aurorae are accompanied by a complete cessation of echoes which is ascribed to the formation of an asorbing layer below the E-layer.[1]

The radio observations during this auroral display confirm these results. During the appearance of the auroral arc passing over zenith, the E-Echoes appeared with quite usually great amplitudes. Fig. 13 shows a part of a record taken during the auroral display. The echoes appearing indicate a critical frequency of the E-layer of 7.4 Mgc/sec which corresponds to a maximum electron density of 10.2×10^5 electrons/cm^3 assuming the critical frequency to be represented by the ordinary component. The height of the E-layer was 125 km. On the record, the F_2-echoes are seen to appear as scattered reflections having a critical frequency at 5.1 Mgc/sec.

In comparison, the echoes appearing at the same hour two days before, October 25th, when no aurorae and earth-magnetic disturbances appeared, are reproduced. The echoes appearing on this day are F_2-echoes appearing in the interval 1.0 to 6.1 Mgc/sec with some spurious reflections from the E-layer up to 1.96 Mgc/sec. Besides the echoes from the main F-layer, scattered reflections from a number of layers above are visible.

[1] In fig. 11 the scales are different in vertical and horizontal directions in order to demonstrate the height-effect distinctly; thus the magnitude of the earth's curvature is not correct when measured with the scale in a vertical direction.

[1] Appleton, Naismith and Builder: Nature, *132*, 340 (1933). Harang: Gerl. Beitr. Geophysik, *46*, 438 (1936), Terr. Mag. *41*, 152 (1936), Geof. Publ. vol. XI, No. 17, (1937).

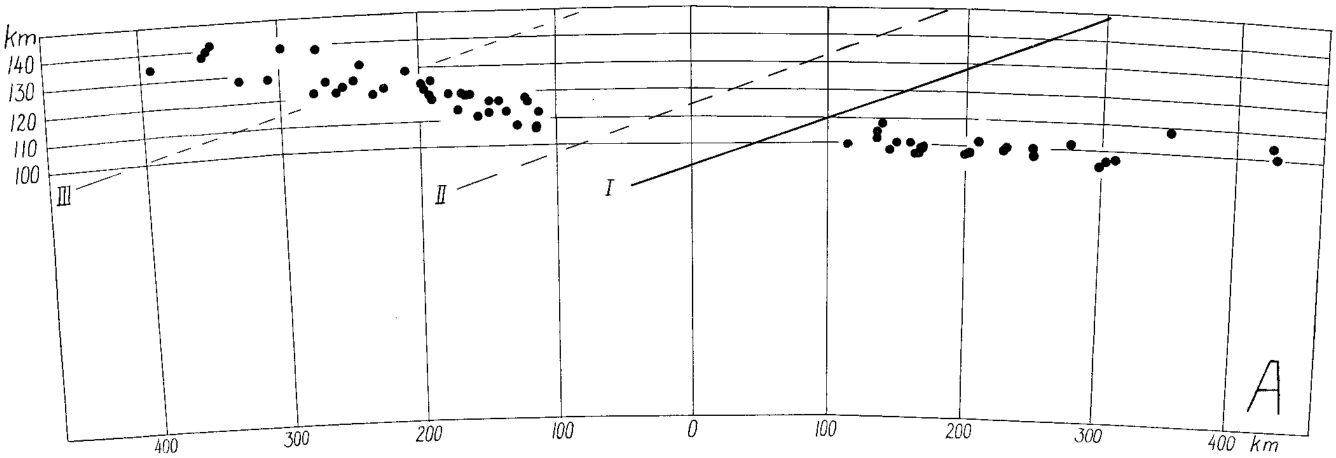

Fig. 11 A.

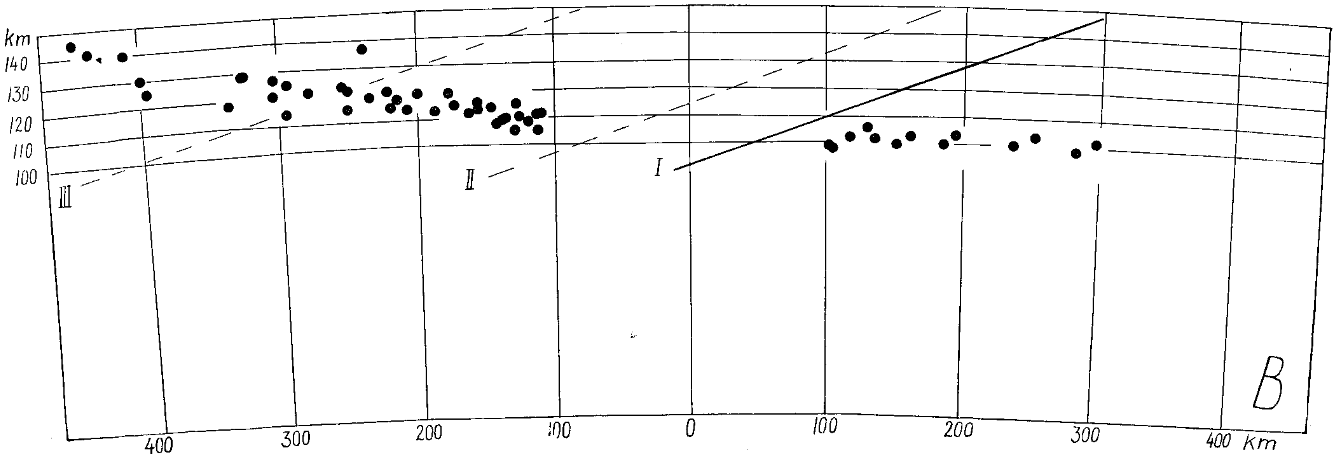

Fig. 11 B.

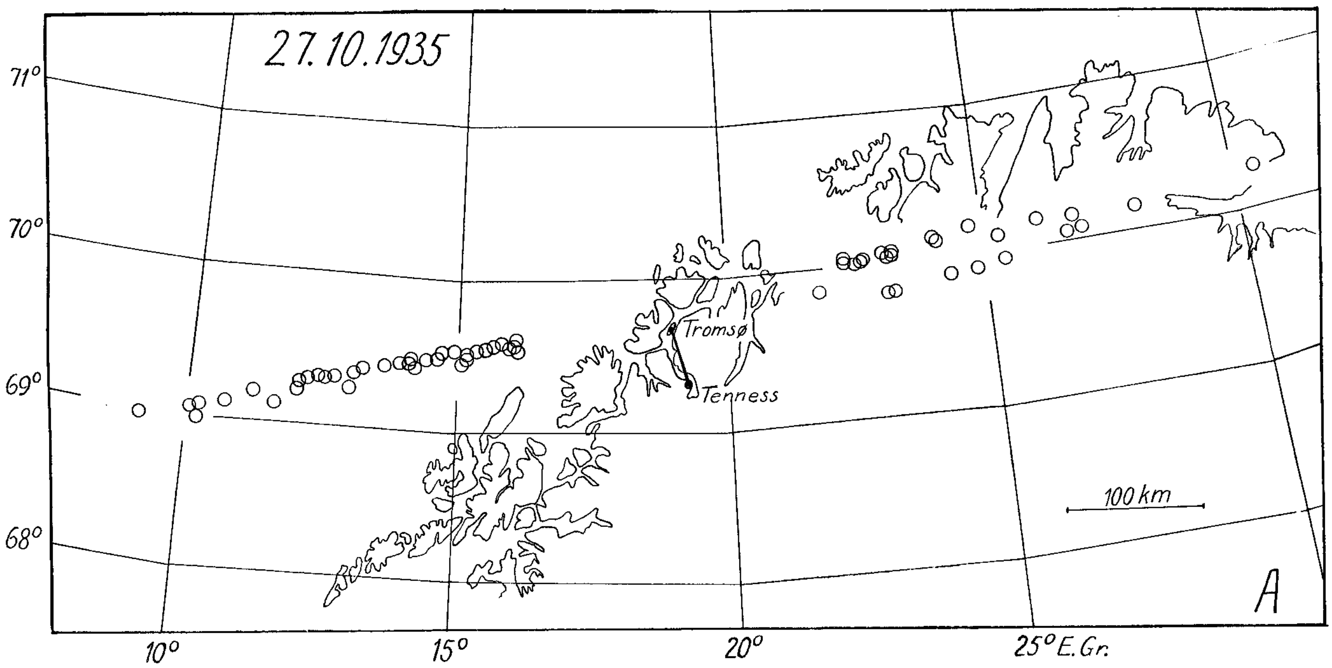

Fig. 12 A.

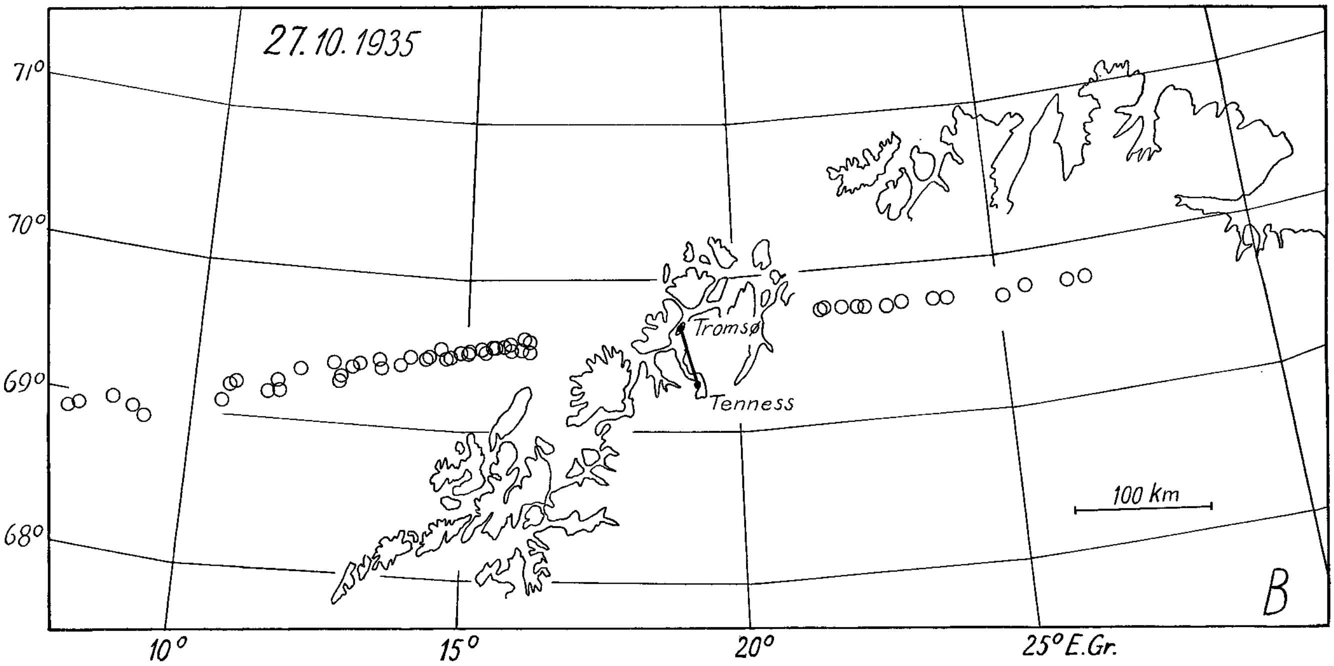

Fig. 12 B.

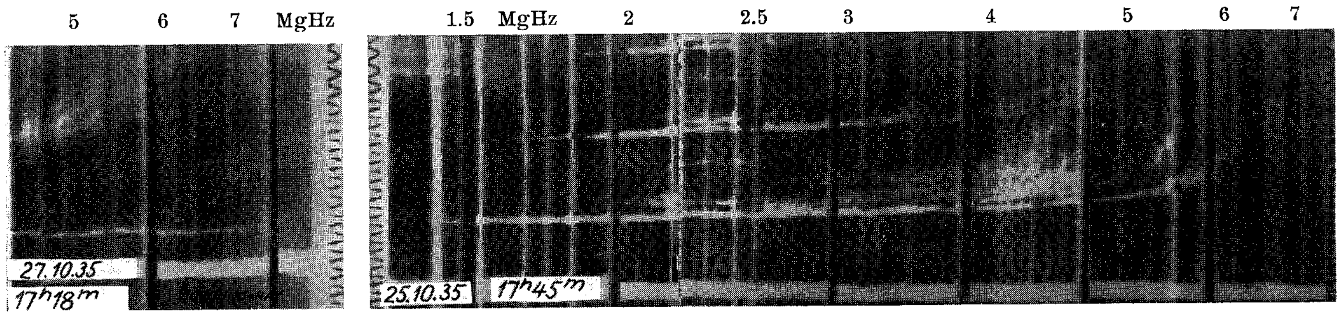

Fig. 13.

§ 3 f. 15.2.1936. Sunlit auroral Arc.

A faint, diffuse auroral arc of the usual green yellow colour appeared in the luminous afternoon sky about 35° above the horizon in the north at $17^h 20^m$ MET.

We succeeded in obtaining communication with Tenness during $17^h 25^m$—$17^h 32^m$ and 24 pairs of photographs were taken. On the photographs of the arc in the west and north the most intense stars in *Lyra-Cygnus* and *Ursa Major* could be traced out of the luminous background from the afternoon sky. On the plates of the eastern part of the arc in *Leo* it was impossible to trace out these less intense stars and the photographs had to be rejected.

From $17^h 32^m$ to $17^h 44^m$ communication with Tenness was broken, the sky meanwhile rapidly becoming covered by clouds. A new arc (III) appeared in the north and 12 pairs of photographs were taken

The following pictures conld be used for height determinations:

Table 4.

No.	MET	Time of Exposure	Constellation of Stars	
1	$17^h 25^m 32^s$	4 sec.	Lyra-Cygnus	I
2	51	8 »	U. Maj.	
3	57	4 »	»	
4	26 07	5 »	»	
5	30	4 »	Lyra-Draco	
6	27 58	11 »	Lyra-Draco	II
7	29 21	6 »	»	
8	57	4 »	U. Maj.	
9	44 42	11 »	U. Maj.-Bootes	III
10	50	5 »	»	
11	45 07	3 »	»	
12	15	6 »	»	
13	24	4 »	»	
14	46 30	3 »	»	
15	37	4 »	»	
16	44	5 »	»	

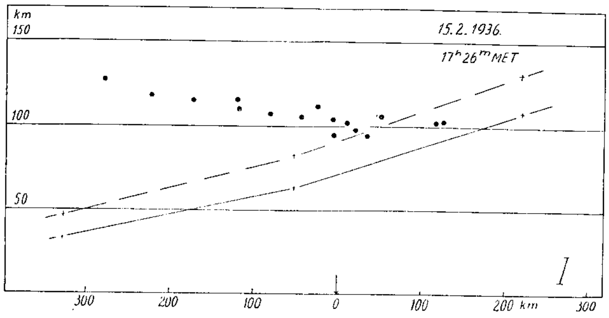

Fig. 14 a.

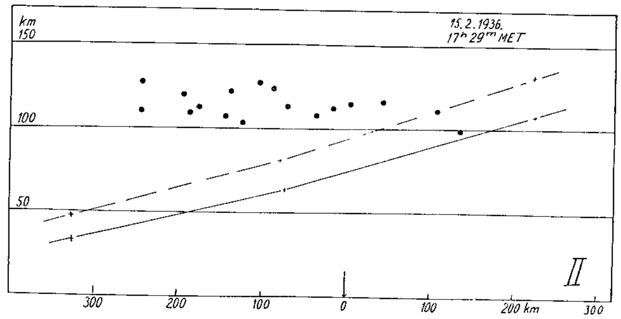

Fig. 15.

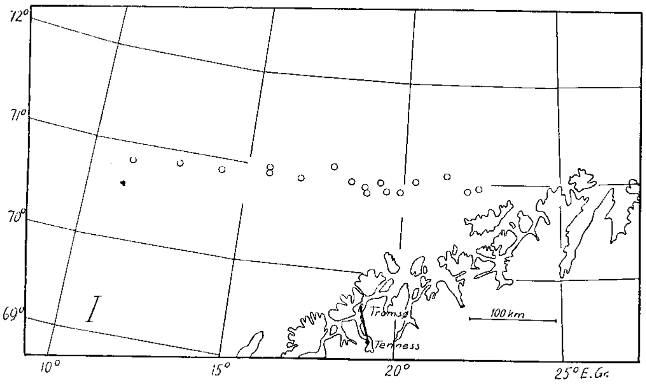

Fig. 14 b.

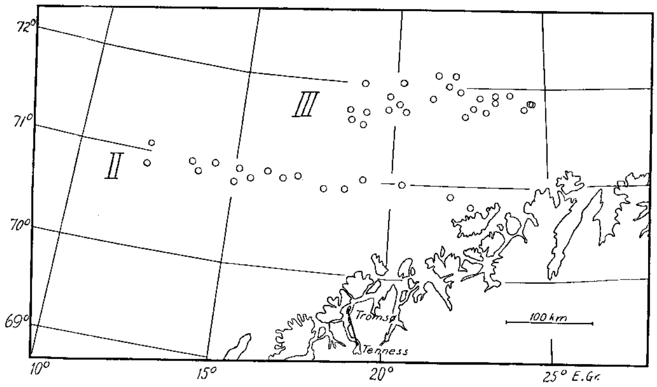

Fig. 16 b.

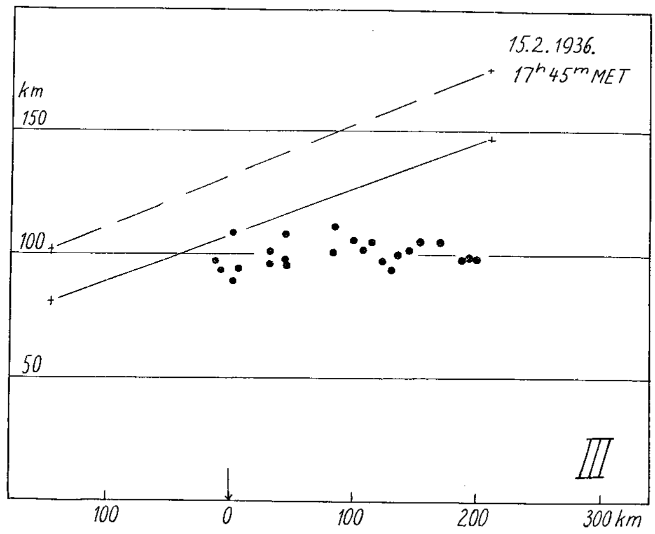

Fig. 16 a.

The heights and horizontal projections of the auroral points selected on the lower border are shown in figs. 14, 15, and 16.

The distribution of the heights indicates that the errors in the single height determination are somewhat greater than, for instance, of the arc of 27. 10. 1935. This is due to the low intensity of the arc which made accurate determination of the lower border on the luminous background when projecting the photographs somewhat uncertain.

The characteristic feature in the distribution of the heights from the dark to the sunlit atmosphere is undoubtedly correct. The heights increase from 100—105 km in the dark atmosphere to about 120 km at the point where the atmosphere is illuminated by the sun-rays from 40 km and upwards.

The earth-magnetic records show during the appearance of the arc a moderate positive perturbation in H of about 170 γ.

§ 3 g. 16. 2. 1936. Sunlit and red-coloured aurorae.

Expecting the sunlit aurorae on the previous evening to reappear, preparation for parallactic photography was made early in the afternoon and telephone line to Tenness, this being a Sunday, was at our disposal.

The first very faint, diffuse auroral bands and arcs appeared in the north in the luminous afternoon sky at $17^h 10^m$ MET. The first 29 pairs of photographs taken between $17^h 15^m$ and $17^h 19^m$ could not be used for height-measurements as it was impossible to trace out even the most intense stars in *Cygnus* from the strong blackening on the plates, even with exposures down to 3—6 sec. From $17^h 14^m$ to $18^h 48^m$ 146 pairs were taken. From $18^h 32^m$ to $18^h 40^m$ a very intense auroral arc, partly appearing with a faint red-coloured lower edge, was photographed.

The results of the height determinations from the most interesting pictures will be given below. Pictures taken in rapid succession of the same aurorae are joined in groups in table 5, and figs. 17—26 show the heights and the horizontal projections of the auroral points selected along the lower borders.

Two effects on the heights of the lower border of auroral bands and arcs are demonstrated in figs. 17—26, the one is the increase of the heights in the sunlit atmosphere when going from the dark to the sunlit atmosphere, the other is the lowering of the heights of arcs and bands when the lower edge shows a more or less distinct red colouring.

The scattering of the auroral points lying in the sunlight is due to the diffuse lower border which was difficult to draw precisely on the projections owing to the strong background.

The red colouring was in all cases faint. In an earlier series of photos taken of an auroral arc with an intense red-coloured lower border the heights of

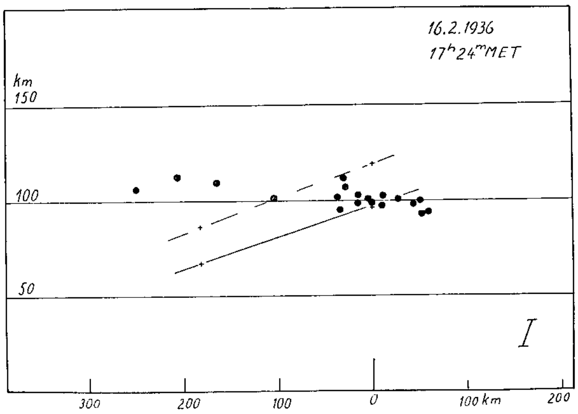

Fig. 17 a.

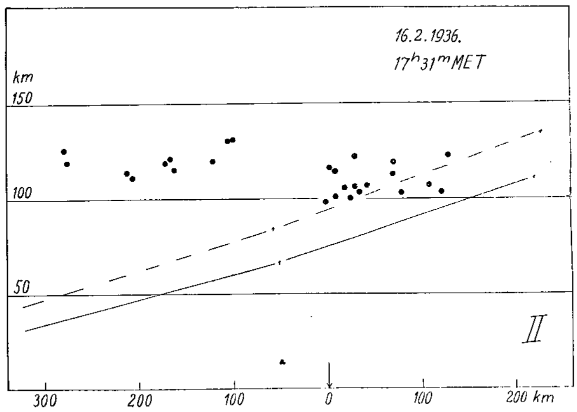

Fig. 18 a.

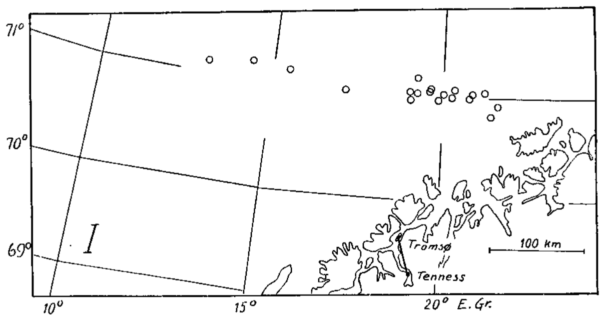

Fig. 17 b.

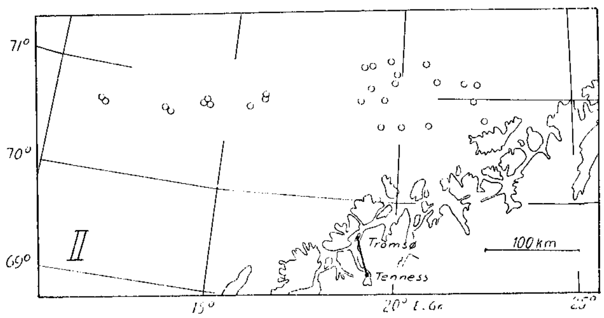

Fig. 18 b.

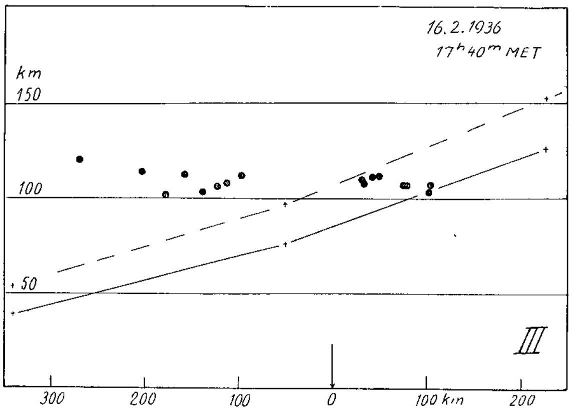

Fig. 19 a.

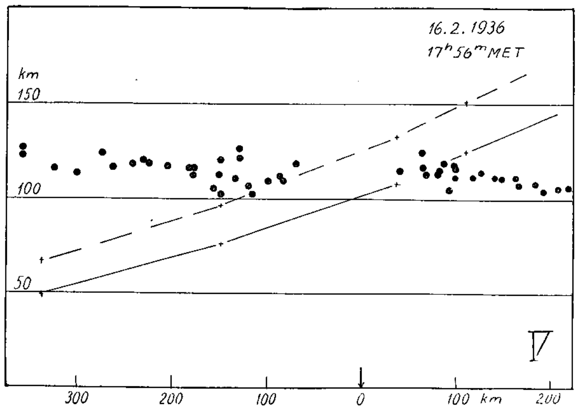

Fig. 21 a.

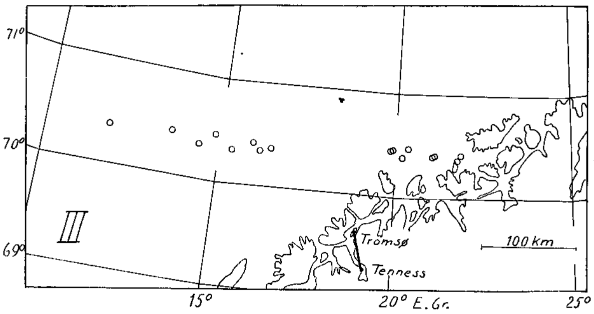

Fig. 19 b.

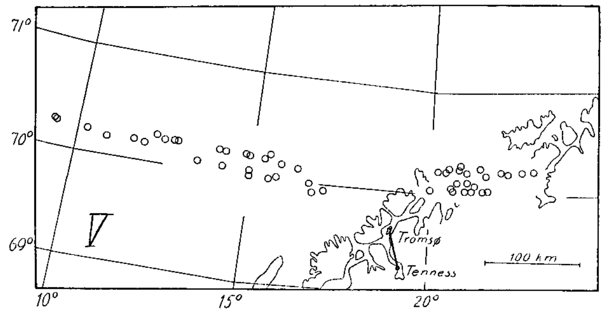

Fig. 21 b.

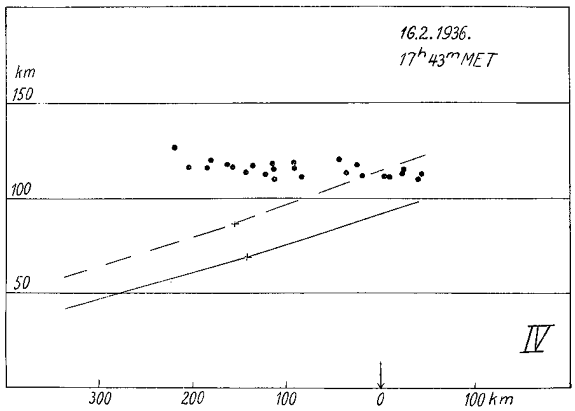

Fig. 20 a.

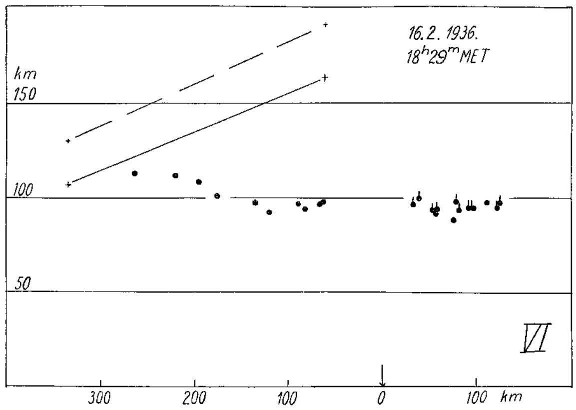

Fig. 22 a.

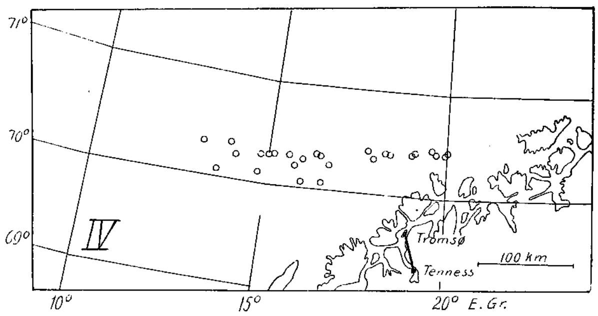

Fig. 20 b.

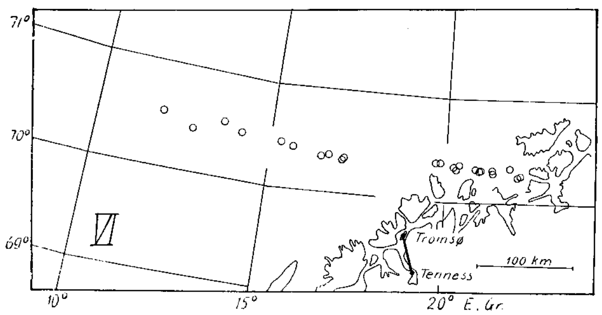

Fig. 22 b.

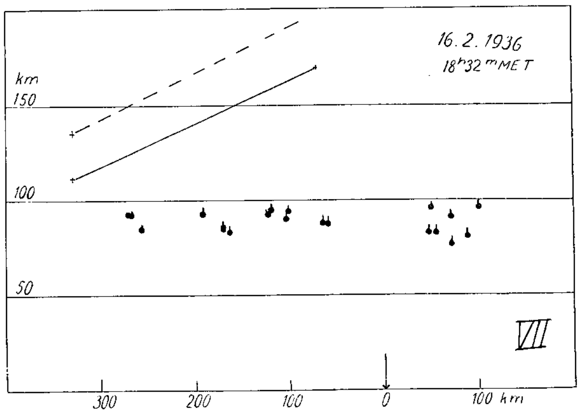

Fig. 23 a.

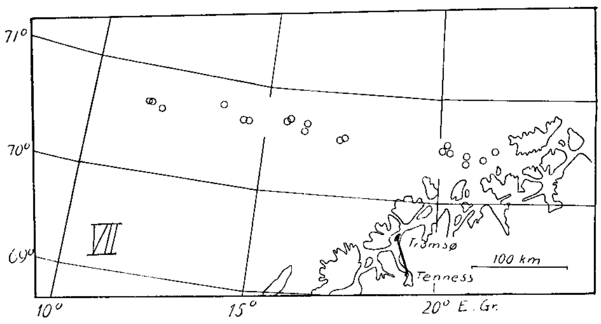

Fig. 23 b.

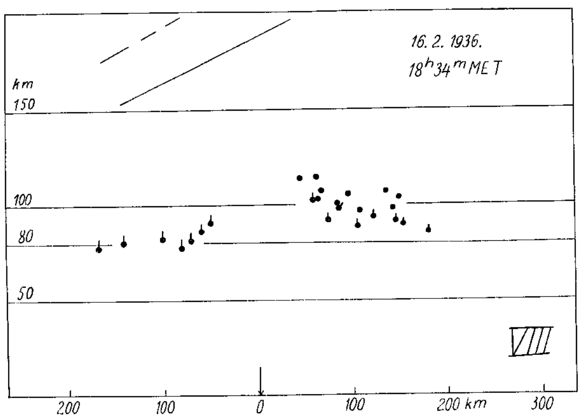

Fig. 24 a.

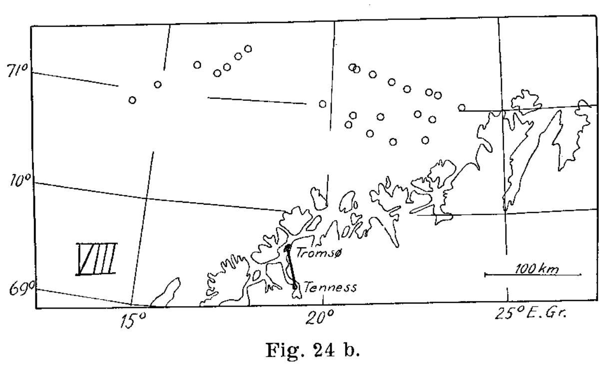

Fig. 24 b.

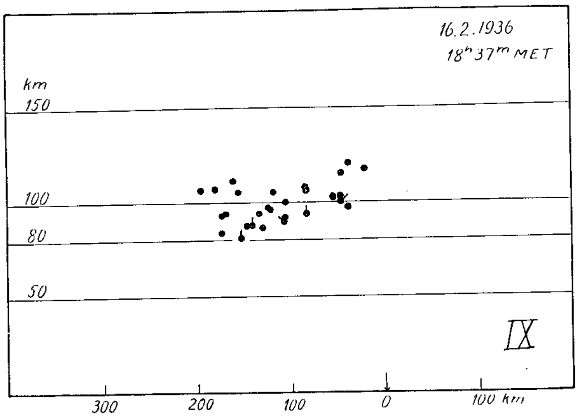

Fig. 25 a.

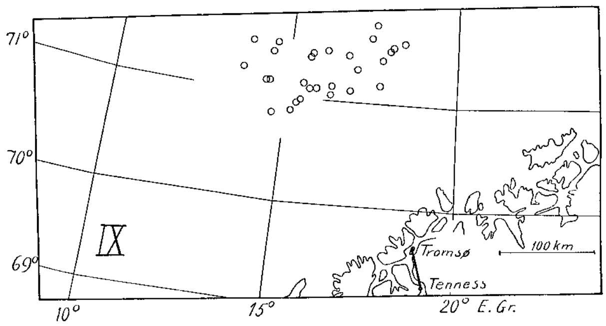

Fig. 25 b.

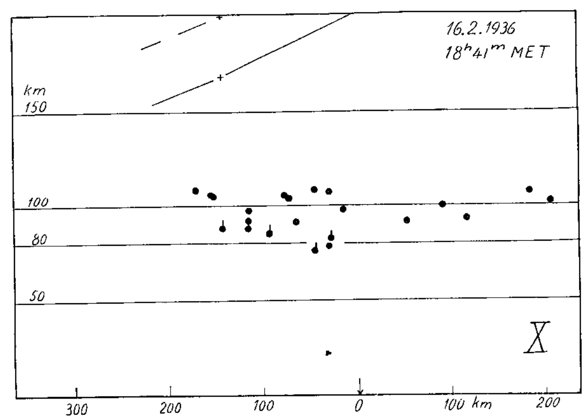

Fig. 26 a.

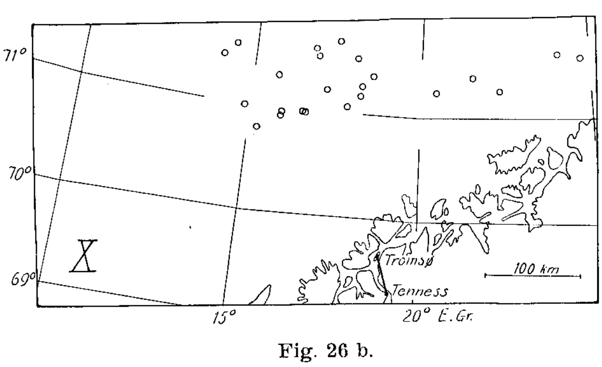

Fig. 26 b.

Table 5.

No.	MET	Time of Exposure	Constellation of Stars	Notes
1	$17^h\ 22^m\ 30^s$	7 sec.	U. Maj.	Group I. A very faint homogeneous arc extending from east to west. Of the 13 photos taken, only one in 5 could trace the stars in the intense blackening from the luminous afternoon sky.
2	40	4 »	»	
3	24 27	5 »	»	
4	33	5 »	»	
5	26 15	5 »	Cygnus	
6	17 26 42	6 »	U. Maj.	Group II. The same faint homogeneous arc. The arc is now moving to the south.
7	57	5 »	»	
8	28 19	3 »	»	
9	26	4 »	»	
10	34 08	6 »	Cygnus	
11	18	5 »	»	
12	26	4 »	»	
13	47	5 »	U. Maj.	
14	39 34	9 »	U. Maj.	Group III. The same homogeneous arc. The arc is now more intense.
15	47	6 »	»	
16	40 16	6 »	Cygnus	
17	26	7 »	»	
18	17 42 00	4 »	U. Maj.	Group IV. The same homogeneous arc.
19	13	5 »	»	
20	45	9 »	Cygnus	
21	55	9 »	»	
22	50 18	7 »	»	
23	17 50 29	7 »	Cygnus	Group V. The same homogeneous arc. The arc is now of medium intensity and develops gradually into an arc with ray structure in the last pictures.
24	57	5 »	»	
25	51 08	11 »	»	
26	20	7 »	»	
27	52 21	4 »	U. Maj.	
28	30	6 »	»	
29	49	11 »	Cygnus	
30	56 30	18 »	Leo	
31	42	13 »	»	
32	18 4 09	4 »	U. Maj.	
33	30	33 »	»	
34	18 29 17	7 »	U. Maj.	Group VI. The first three photos are of a yellow green arc, on the two last pictures, the lower border had a faint red colour (the heights of the red-coloured arc are in fig. 22 a and the following figures marked by ↓).
35	32	5 »	Cygnus	
36	41	4 »	»	
37	51	6 »	U. Maj.	
38	30 02	5 »	»	
39	18 31 27	7 »	Cygnus	Group VII. The same arc; the intensity is now very great, exposures of 4 sec. give quite over-exposed pictures. On all these pictures the lower border of the arc was very faint red.
40	35	5 »	»	
41	40	4 »	»	
42	51	4 »	»	
43	32 33	9 »	»	
44	18 33 32	5 »	U. Maj.	Group VIII. The same arc. On the first two photos the colour was the usual green yellow, on the next two the lower border was a faint red. On the last the lower border was a more intense red. (The heights from this picture are indicated in fig. 24 a to the left.)
45	42	9 »	»	
46	34 19	9 »	»	
47	31	8 »	»	
48	50	7 »	Lyra	
49	18 35 36	23 »	Lyra	Group IX. The same arc. On the first four photos the colour was the usual green-yellow, on the last the lower border was a faint red.
50	36 04	33 »	»	
51	44	28 »	»	
52	37 27	51 »	»	
53	38 25	29 »	»	
54	18 40 00	10 »	U. Maj.	Group X. The same arc. On the second picture the lower edge was faint red-coloured.
55	16	11 »	Lyra	
56	34	12 »	»	
57	50	9 »	»	
58	41 07	9 »	»	

the lower border went down to 65—70 km.[1] It is therefore probable that the more or less distinct red colouring at the lower edge is an effect of the gradual increase in the penetration power of the electrically-charged particles producing the aurorae.

Spectral observations of the red-coloured aurorae.

With a glass spectrograph of high light power one spectrum of arcs appearing with a faint red-coloured lower border was photographed on this evening. On the following evening two spectra of normal yellow green aurorae were taken on a plate from the same stock. Both plates were developed in a standard developer. On Plate I No. 7 the three spectra in red and green are reproduced.

The auroral spectrum in red consists mainly of the doublet 6300 and 6360 Å and a number of bands by 6580 Å. Fabry-Perot pictures taken of the auroral spectrum in red[2] show that at least the line 6300 Å is an atomic line and the most probable identification of the line 6300 Å and 6360 Å is the two "verbotenen" Oxygen lines OI ($^3P_1$—$^1D_2$) and ($^3P_2$—$^1D_2$).[3] The bands at 6580 Å are due to the Nitrogen molecule, this is also the case with a fainter group of bands at 5890 Å which usually occurs in the auroral spectrum.

On spectrum 7 a of the red-coloured arcs, the red doublet 6300 and 6360 Å is visible as narrow lines, the Nitrogen bands at 6580 Å are faint.

In spectrum b and c of yellow-green aurorae the relative intensity has changed; the Nitrogen bands at 6580 Å occur with considerable intensity. A different structure in the spectra is also visible. In spectrum 1 the atomic line doublet occurs as narrow lines on the faint background, in spectrum 2 and 3 it is difficult to see the doublet structure of 6300 and 6360 Å on account of other lines or bands superimposed — according to Vegard, one should in this spectral region also expect a number of Nitrogen bands.

The red colouring at the lower edge is therefore due to the red Oxygen lines, in accordance with earlier results from filter photographs of red coloured aurorae.[4]

1 Harang and Bauer: Gerl. Beitr. Geophys. *37* (1932) 109.
2 Harang and Vegard: Nature *135* (1935) 542.
3 Paschen: Naturwiss. *18* (1930) 752.
4 Harang: Gerl. Beitr. Geophysik *44* (1935) 229.

§ 3 h. 17. 2. 1936. Bands and arcs.

Sunlit auroral bands and arcs appeared in the luminous afternoon sky in the west at 17^h 25^m MET, and between 17^h 30^m and 19^h 30^m 78 pairs of photographs were taken.

The first 15 pairs which were taken of sunlit aurorae in the west could not be used for height

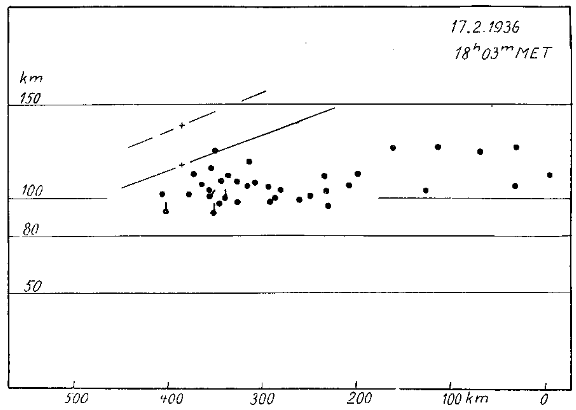

Fig. 27.

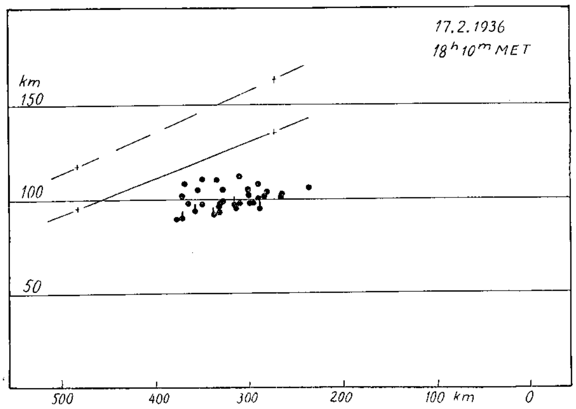

Fig. 28.

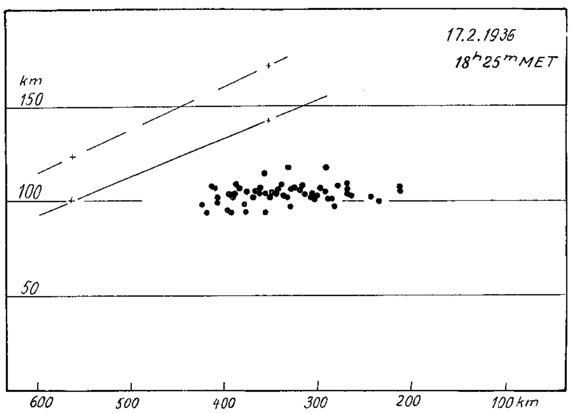

Fig. 29.

measurements as it was impossible to trace the stars in the strong blackening from the afternoon sky. Those taken later were only of aurorae lying in the park atmosphere just behind the shadow line. The distribution of heights of the lower boundary of a number of arcs and bands is given in figs. 27, 28, and 29. It is evident that the mean height of this aurorae lying just behind the shadow line is 100—110 km. On two photographs the lower edge of an arc was observed as faint red, the heights of the lower boundary from these pictures are marked by ↓ in figs. 27 and 28. As on the preceding evening, the red colouring is accompanied by a decrease of the heights.

The earth-magnetic registrations on the 16 and 17. 2. show a strong positive perturbation in H at noon, and during the appearance of the sunlit aurorae in the west the perturbation is still positive.

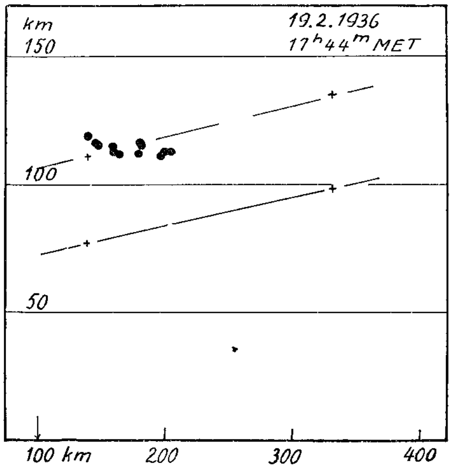

Fig. 30 a.

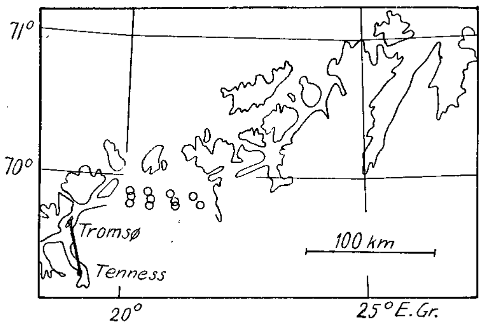

Fig. 30 b.

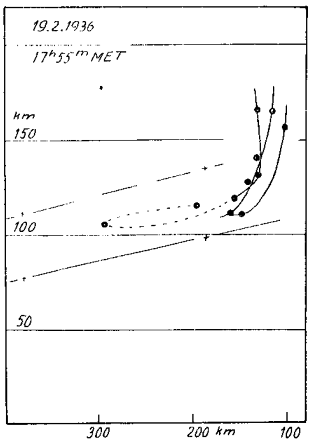

Fig. 31.

§ 3 i. 19. 2. 1936. Sunlit bands and draperies.

Sunlit auroral draperies appeared in the west at $17^h 40^m$ MET. The first 12 pairs of photographs taken af these sunlit aurorae could not be used for height measurements as it was impossible to trace the stars in the strong blackening of the afternoon sky.

Fig. 30 shows the heights and horizontal projections of a sunlit arc appearing in *U. Maj.* determined from three pictures. The heights indicate the usual increase of the heights in the sunlit part of the atmosphere.

Later in the evening a number of draperies and bands of complicated and irregular forms appeared and 108 pairs of photographs were taken. The heights of these aurorae have been calculated, but as the results only demonstrate the heights of aurorae usually appearing at night, we will not give any detailed report regarding them.

We will only give the position in space relative to the shadow line of draperies occurring and photographed after to the auroral are first mentioned. The upper part of this drapery, lying in full sunlight, did not reach higher than the draperies photographed later in the evening and lying in the dark atmosphere.

§ 3 k. 21. 2. 1936. Sunlit bands, draperies, and rays, red-couloured arcs and bands.

The first faint aurorae were seen at $18^h 10^m$ MET and the parallactic photography was started at $18^h 15^m$. In less than two hours 114 pairs of parallactic photographs were taken, of which a number were of sunlit or red-coloured aurorae.

The sunlit aurorae on this evening appeared as draperies of more irregular forms than the arcs and

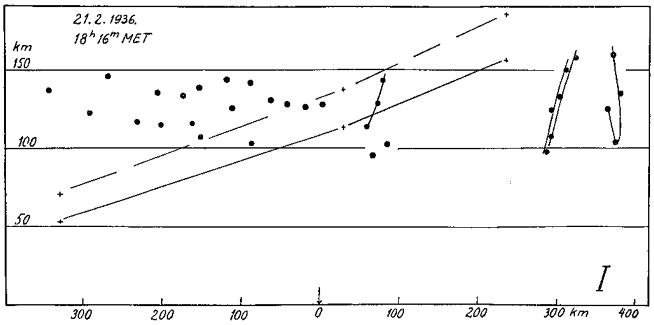

Fig. 32 a.

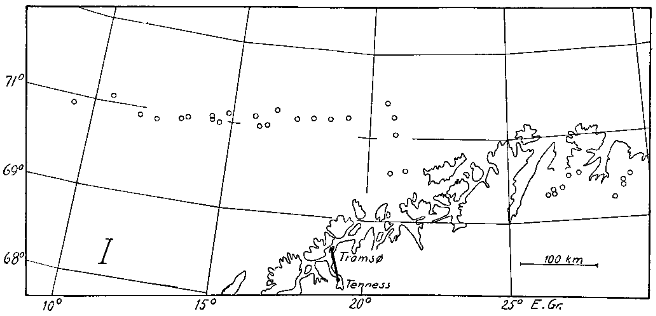

Fig. 32 b.

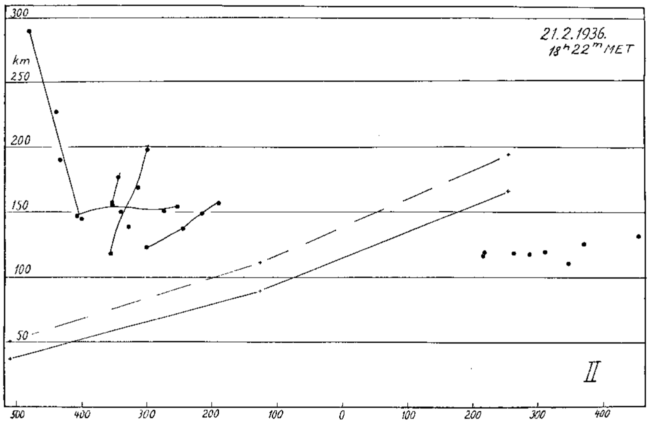

Fig. 33.

bands appearing on the previous evenings during this auroral period. We will therefore only give, by a number of figures, a condensed presentation of the heights measured.

Group I, fig. 32 shows the height and horizontal projections determined from 10 pairs of photographs taken during the time interval $18^h 15^m 18^s$—$18^h 18^m 50^s$. The sunlit aurorae in the west consisted of draperies and bands and the points indicated in fig. 36 show the lower limit of the forms. In the east two draperies in the dark atmosphere went down to 98 and 102 km. The sunlit aurorae in the west show a considerable greater height of the lower boundaries. The great variation of heights of the different forms in the west during this evening was real and not due to accidental errors.

Group II, fig. 33 shows the height distribution of a number of draperies photographed at $18^h 20^m 03^s$—$18^h 23^m 33^s$. The upper limit of the sunlit draperies in the west extend to a height of 290 km.

Group III, fig. 34 shows the height distribution of the lower borders of draperies and bands photographed at $18^h 23^m 47^s$—$18^h 24^m 34^s$.

Group IV, fig. 35 shows the height distribution of draperies and bands photographed at $18^h 25^m 36^s$—$18^h 26^m 15^s$. These forms are lying in the dark atmosphere just behind the shadow line, and the heights are smaller than those of the sunlit aurorae in the previous groups.

Group V, fig. 36 shows the heights determined from three series of pictures. The first series consisted of three photographs of faint rays and draperies photographed in the west during the time interval $18^h 27^m 32^s$—$18^h 28^m 43^s$ MET. At the same time a fairly intense drapery-shaped band appeared in the

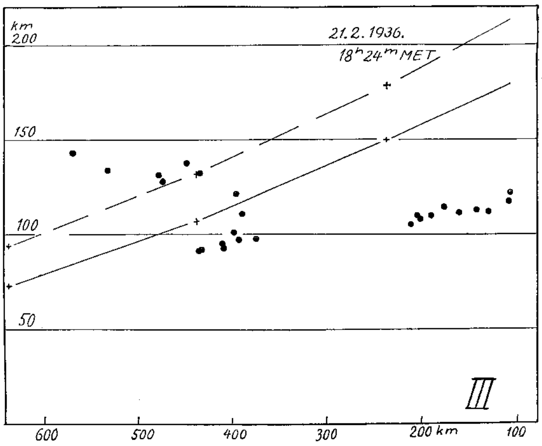

Fig. 34.

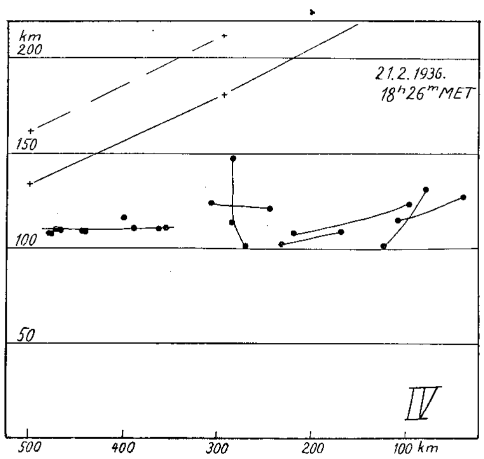

Fig. 35.

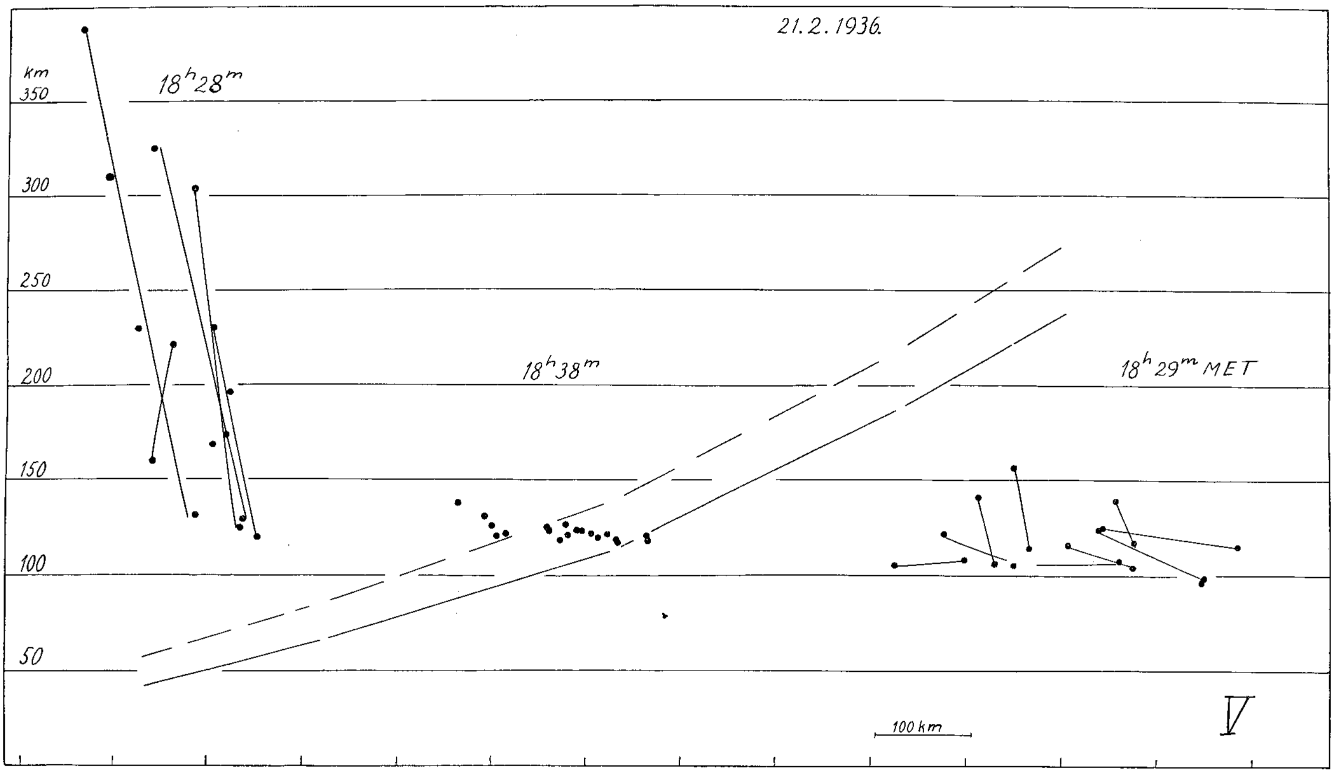

Fig. 36.

east of which three pictures were taken during the time interval 18h 29m 11s—18h 29m 39s. The sunlit rays and draperies in the west attain a maximum height of 389 km, the lower limit was 120—130 km. The lower limit of the drapery-shaped band lying in the shadow in the east was 105—110 km, and the maximum heights of the streamers were 160 km.

About nine minutes later a very intense drapery-shaped band appeared in the west, but now much nearer Tromsø than the group of rays first mentioned. The heights of the lower border determined from six pictures taken during the time interval 18h 37m 24s —18h 38m 35s was 120—130 km. The band was partly sunlit, and as shown in fig. 36 the heights of the lower border decreasing when approaching the shadow line.

Group VI, during the time interval 18h 39m 37s —18h 56m 51 MET a considerable number of pictures of intense auroral bands and arcs was obtained, all lying in the earth's shadow. The earth-magnetic perturbation was now very intense and in a number of cases it was noticed that the arcs and bands showed a slight crimson colour at the lower edge, although the red-colouring was never predominant. The pictures of aurorae which showed traces of red colouring during the photography were noted in the diary while the work went on. From the material collected, 52 pairs of photographs were reduced for height determinations and fig. 37 shows the distribution of heights along the lower border. The considerable scattering of the individual points is partly due to the fact that in a number of cases ray-structure appeared, and one usually then got a considerable variation of the heights along the lower border when going from the strong light patches to the weaker parts of aurorae.

The frequency curves in fig. 37 to the right show that the aurorae with traces of red colouring, on an an average, have 5—7 km smaller heights than the usual yellow-green types of aurorae.

In this connection, we would mention that the lowering of the heights of very intense and red-coloured aurorae compared with the heights of faint and quiet auroral draperies, was shown by Størmer in the height statistics of his expedition to Bossekop in 1913.[1]

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[1] Forhandlinger ved 16. skand. naturforskermøte 1916, p. 126.

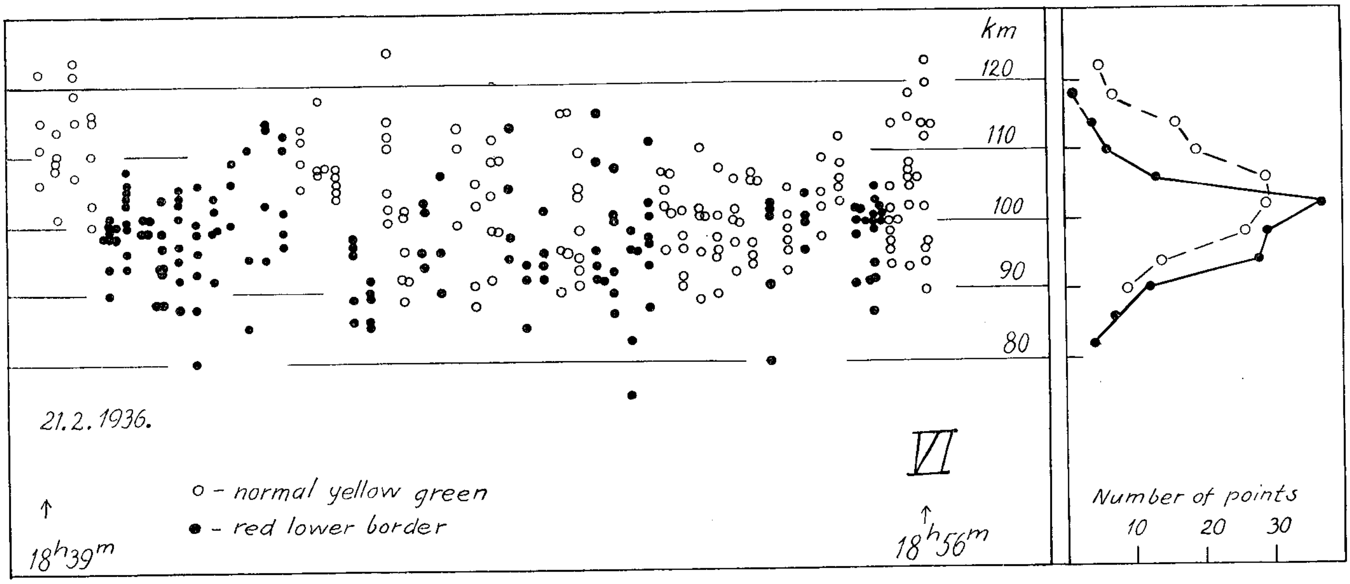

Fig. 37.

§ 3 l. 23.2.1936. Sunlit draperies and bands.

During the time interval $18^h 13^m$—$22^h 25^m$ MET, 98 pairs of parallactic photographs were taken. The first plates were of sunlit auroral bands and draperies, the rest being of the usual yellow-green arcs, bands, and draperies. As the heights of these normal types were lying in the usual height interval, no results of their height determinations will be given.

The sunlit auroral bands and draperies were faint and had diffuse outlines; the accuracy in the height determination of the individual points is therefore somewhat limited. We will therefore only give the results of the height dererminations from the best series of pictures — 4 pairs taken during the time interval $18^h 28^m 10^s$—$18^h 28^m 54^s$ MET, and, as a comparison, the heights of auroral bands lying in the shadow determined from 4 pairs taken during the interval $19^h 56^m 57^s$—$19^h 57^m 55^s$ MET.

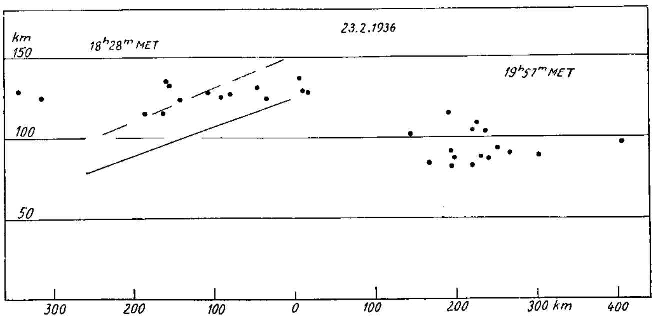

Fig. 38.

As seen from fig. 38, the mean height of the sunlit aurorae was 125 km, that of the aurorae lying in the shadow, 95 km. The aurorae lying in the shadow were photographed 90 minutes after the sunlit aurorae, there thus being no continuous connection between these two groups of aurorae.

§ 3 m. 26.2.1936. Sunlit draperies.

Sunlit aurorae appeared in the west at $18^h 15^m$ MET. Between $18^h 31^m$ and $18^h 57^m$ 48 pairs of parallactic photographs of aurorae lying in the full sunlight were taken. As the aurorae on this evening consisted of fairly irregular and faint bands, draperies, and rays, the height determinations are not so accurate as on

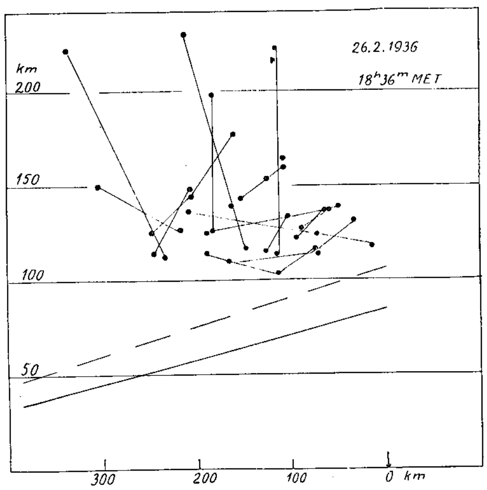

Fig. 39.

Table 6.

No.	MET	Time of Exposure	Constellaon of Stars	
1	$20^h\,48^m\,51^s$	15 sec.	Aldebaran	I
2	49 14	20 »	»	
3	50 1	9 »	Gemini	
4	17	12 »	»	
5	53 55	7 »	Cygnus	II
6	54 06	8 »	»	
7	18	10 »	»	
8	26	9 »	»	
9	21 15 40	12 »	Andromeda	III
10	51	9 »	»	
11	16 41	15 »	Vega	IV
12	17 33	10 »	»	
13	24 50	11 »	Cygnus	V
14	25 02	8 »	»	
15	17	6 »	»	
16	27	6 »	»	
17	37	8 »	»	
18	47	8 »	»	

the previous evenings. We will therefore only give a condensed representation of the height-determinations during the interval $18^h\,31^m\,55^s$—$18^h\,39^m\,47^s$ MET by fig. 39. The lower boundary of the draperies and bands are indicated by lines through the selected points. The maximum upper limit attained by the streamers was 239 km. As seen from fig. 39, the lower boundary of the bands and draperies lie between 110 and 140 km with the greatest frequency at about 125 km, which is 15—20 km higher than for aurorae lying in the shadow.

§ 3 n. 24. 3. 1936. Sunlit arcs and bands.

Between $20^h\,47^m$ and $21^h\,47^m$ MET 42 pairs of parallactic photographs were taken of different auroral forms, the greater number lying partly in the sunlit atmosphere. The results of the height determinations from the following pictures will be given.

Group I, fig. 40 shows the position of a diffuse arc extending from the dark to the sunlit atmosphere. The arc was faint, the heights of the lower border in the dark atmosphere show the somewhat great value of 115—120 km. When approaching the shadow line the heights increase, and in the sunlit atmosphere the heights are 125—135 km.

Group II, fig. 41 shows the position of an arc with ray-structure. The light intensity of the arc was considerable and for some seconds a faint crimson

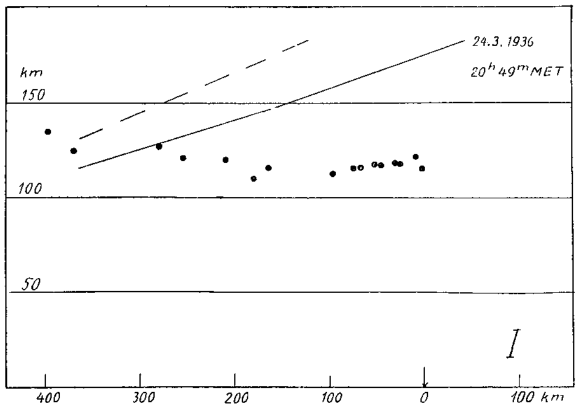

Fig. 4.

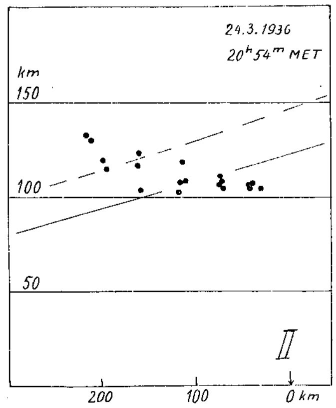

Fig. 41.

edge at the lower border was visible. Compared with the first arc, the lower border of this arc shows a considerable lower value. In the dark atmosphere the heights are about 105 km; when approaching the sunlit atmosphere the heights exhibit a rapid increase up to 123 km in the full sunlight.

Group III, fig. 42 shows the position of a diffuse, double arc with a faint double ray appearing simultaneously. These aurorae were almost completely sunlit. The ray extends up to the considerable height of 359 km. The heights of the lower border of the diffuse arcs lying in the sunlit atmosphere show the fairly high value of 140—150 km; in the vicinity of the shadow line the heights decrease to 120—130 km. The considerable scattering of the individual points is due to the diffuse lower border, which makes a most precise height determination difficult.

Group IV, fig. 43 shows the position of ray penetrating the shadow line. The outlines of the projections are given in fig. 44 and a reproduction

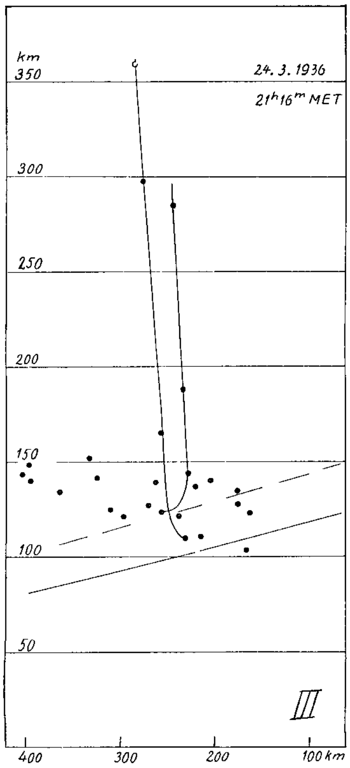

Fig. 42.

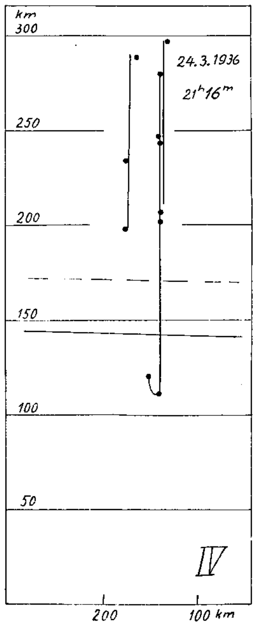

Fig. 43.

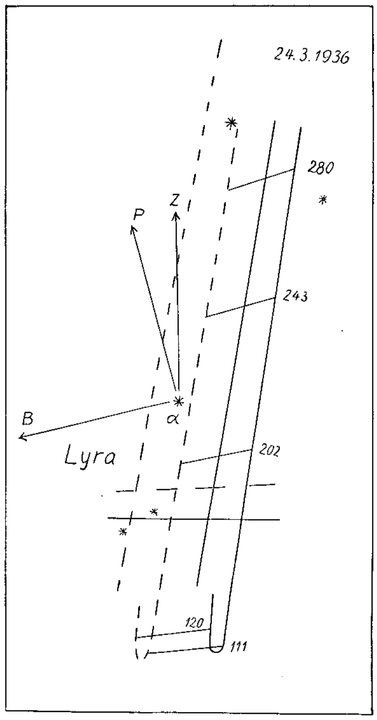

Fig. 44.

of the photographs is given on Plate I, No. 8. As previously mentioned, Størmer[1] has shown that on a ray penetrating the shadow line, there may be a discontinuity in the luminosity of the ray. In this case this seems not to occur, and, as seen from the reproduction of the photographs there is no change in the luminosity of the ray when passing through the shadow line.

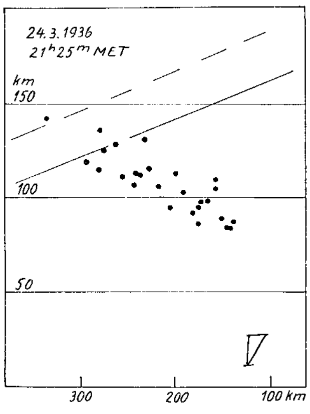

Fig. 45.

[1] Z. S. Geophysik, *5*, 177, 1929.

Group V, fig. 45 shows the position of an arc with ray structure. The strong increase of the heights on the dark side of the shadow line is somewhat unusual.

§ 4. The solar and earth-magnetic activity during the great auroral period in February 1936.

It is interesting to note that the astronomer ons the 14th, observed a quite unusual intense solar activity by means of the spectroscope (Newton: Nature, *137*, 363 (1936) and The Journ. of the Brit. Astr. Ass. *46*, 196 (1936)). A group of sunspots not remarkable for their size crossed the central meridian on the 14th. By means of the spectrohelioscope, considerable activity in the form of bright eruptions was recorded from the 7th to 14th. On the 14th at noon, an eruption of quite unusual strenght was observed and further observations during the day showed the greatest radial velocities of an eruption, measured in $H\alpha$-light, observed at the Greenwich observatory (since 1930). It is interesting to note that these eruptions of quite unusual intensity are followed by the auroral period of 15—17th, during which the rarely occurring sunlit aurorae were photographed.

An inspection of the earth-magnetic registrations of the observatory show that during the afternoons and evenings when the sunlit aurorae appeared, a strong *positive* polar storm occurs. Compared with the following negative storm during the night, this positive storm is considerably greater than is usual during earth-magnetic disturbed days. The sunlit aurorae observed, even quiet and faint bands or draperies, have always been accompanied by intense earth-magnetic perturbations. This is not always the case with aurorae occurring during the night; aurorae of low or medium intensity and especially the quiet forms, are often accompanied by fairly small earth-magnetic perturbations.

§ 5. Discussion of the variation of heights of the aurorae when going from the sunlit to the dark atmosphere.

In a number of cases the continual increase of the heights from the dark to the sunlit atmosphere has been demonstrated. Concerning arcs and bands, the most reliable determinations are from the 27. 10. 1935. Except in one case (24. 3. 1936, fig. 45) the aurorae in the dark atmosphere behind the shadow line show a uniform height without systematic variations. The increase of the heights starts at the point where the lower shadow line (for which the atmospheric refraction has been taken into account) cuts the level of the aurorae. We have assumed above that the increase of the auroral heights in the sunlit atmosphere is explained by a lifting of an isobaric surface at heights of 100 km, which is due to a thermal expansion of the sunlit atmosphere. The "night conditions" of the auroral heights which are attained just behind the shadow line indicate that the equilibrium of radiation in the atmosphere is very rapidly attained when the sun-rays disappear.

Concerning the part of the solar spectrum which is responsible for the temperature increase in the border region, the whole ultra-violet part of the spectrum where the strong absorption due to the Oxygen molecule and the ozone occurs, must be excluded, as this part of the solar spectrum must be completely absorbed when passing the atmosphere at grazing incidence. In the region of long waves temperature increase due to energy absorption is possible in the red and infra-red part of the solar spectrum and, as well known, even a small amount of water vapour absorbs a considerable part of the energy of this part of the solar spectrum rich in energy.

The explanation of the increase of the auroral heights as a temperature effect, involves the assumption of a diurnal variation of temperature in the upper part of the stratosphere. Direct measurements of temperature by means of sounding balloons in the lower part up to 20 km have shown that this part of the stratosphere exhibits a seasonal variation of temperature and also a variation with the latitude. Further, the temperature has a minimum at a height of 14—15 km, in the interval 15—20 km, the series of observations show a slight increase in the temperature. Regarding the diurnal variation of temperature in the part of the stratosphere up to 20 km, this is difficult to determine as the main temperature varies with the changing air-masses, but the observations indicate that a diurnal changing variation of temperature must be small. Sir Napier Shaw summarizes the results of observations concerning the diurnal temperature variations of follows:[1] "nothing, above a kilometre, that can be called diurnal variation in the sense used about the surfase."

There thus seems to be a fundamental difference between the magnitude of the diurnal variation of temperature in the lower and upper part of the stratosphere, a difference which most probably is due to different absorption of the solar spectrum at different heights of the atmosphere.

As shown by radio methods,[2] there is a parallel difference in the physical conditions of the atmosphere at the level of the E and F_1-layers (in 120 and 200 km's height) and the F_2-layer (at 220 km and above), where the annual variations of the ion production due to the absorption of the sun-rays are different.

The variation of heights of the sunlit arc from 27. 10. 1935 allows us to estimate the gradual increase in the temperature from the dark to the sunlit atmosphere. We shall make the following assumptions: Complete mixing of the constituents of the atmosphere is assumed for all heights. The dark part of the stratosphere from the auroral region down to 40 km's height is assumed to have a uniform temperature, which we shall take to be of the same magnitude, $225° K$, as the temperature of the excited N_2-molecules measured from the intensity-distribution of the R-branch on the Nitrogen bands in the auroral spectrum.[3] Further,

[1] Manual of Meteorology *2*, 111 (1928).

[2] Appleton: Nature, *136*, 52 (1935), Phys. Rev. *47*, 89, 704 (1935).

[3] L. Vegard: Terr. Mag. *37*, 389 (1932), and L. Vegard and E. Tønsberg: Geophys. Publ. *11*, No. 2 (1935).

Table 7.

Points	D' km	H km	h km	H/h	T °K
A	0	0	0	1.00	225
B	200	42	31	1.36	306
C	300	66	34	1.50	338
D	400	91	58	1.57	353

we assume that the temperature is uniform in vertical direction in the sunlit section of the atmosphere. Regarding the auroral heights as indicating an isobaric level, the pressure p in this level is given by the equation $p = p_0 e^{-(gma/RT)H}$ where p_0 is the pressure along the shadow line, g the acceleration of gravity, m the mean molecular weight, R the universal gas-constant, a the radius of the Earth, H the height from the shadow line to the isobaric surface, and T the absolute temperature. For the points A, B, C, and D in fig. 46, it is easy to show that $H_B/T_B = h_B/T$, $H_C/T_C = h_C/T$, and $H_D/T_D = h_D/T$. We see from table 7 that the absolute temperature T has increased in the proportion 1 : 1.57 when moving from the point where the shadow line cuts the 100 km level, and the density of the air has decreased in the same proportion.

In computing the shadow line, the effect of refraction has been taken into account. Thus the sun's rays, when entering the lower part of the section, have twice passed the earth's atmosphere. One must therefore assume a considerably higher temperature in the part of the sunlit section and the temperature estimates in table 7 must therefore be regarded as a lower limit of the increase in the temperature at heights of 100 km.

It is known from meteorology that an isobaric surface making an angle Φ with the horizontal plane will give rise to geostrophic wind. The velocity in the wind direction is given by the equation (Buys Ballot's law[1]

$$v_x = (g/2\,\Omega_z)\tan\Phi$$

where Ω_z is the vertical component of the angular velocity of rotation of the earth and g has the usual signification.

[1] See for example, V. Bjerknes: Physikalische Hydrodynamik, 477, (Berlin 1933).

The auroral heights on the 27. 10. 1935 indicate an inclination of the assumed isobaric surface corresponding to $\tan\Phi = 0.1$. Substituting the appropriate values for g and Ω_z we get a value for the velocity of $v_x = 7$ km/sec. The direction of the wind will follow the isobars and assuming these to lie at right angles to the direction of the sun's azimuth, the wind-direction will be from north to south. The formula for the wind velocity is independent of any assumptions regarding density and temperature of the atmosphere, and the great velocity computed from the formula is due to the inclination of the assumed isobaric surface which is of quite another magnitude than observed in cyclones in the troposphere. We have here assumed

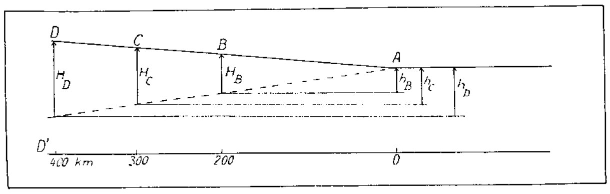

Fig. 46.

the isobars to be straight lines; if the isobars occur as curved lines, the velocity will also depend on the curvature of the isobars and the velocity will be reduced.

The velocity computed is scarcely physically probable, indicating that the assumptions regarding the directions and forms of the isobars and the auroral heights indicating an isobaric surface may not be valid, or that other factors occur which modify the order of magnitude of the wind velocity computed.

The measurements of heights of the luminous night clouds have given valuable information about the horizontal movements in the atmosphere at great heights on the border-line between the sunlit and dark atmosphere. Jesse[1] and of recent years Størmer[2] have made a number of height determinations of these interesting objects. In one case Størmer has determined the velocity and direction of drift of a cloud lying at the height of 75 km having a velocity of 44 to 55 m/sec. The direction of drift was from the sunlit part of the atmosphere towards the earth's shadow with a component to the right. The direction of drift was from the sunlit part of the atmosphere towards the earth's shadow with a component to the right.

[1] Sitz. ber. Ak. Wiss. 1890 and 1891 (Berlin).

[2] Avh. Vid. Ak. I, Math. Naturv. Kl. No. 2, 1933 (Oslo).

The direction of drift was thus at about right-angles to the direction which was to de expected for geostrophic winds.

The successive pictures taken by Størmer of luminous night clouds show rapid changes of the internal structure of the cloud during periods of a few minutes. This indicates that on the border-line between the sunlit and the dark atmosphere at a height of 75 km, strong turbulence occurs which will influence strongly the velocity of a geostrophic wind.

The author wishes to express his sincere thanks to Mr. E. Tønsberg, cand. mag., for valuable discussions regarding the methods for reduction of parallactic photographs and occasional assistance with the photography, and to Mr. S. Jenssen for undertaking the parallactic photography at Tenness, the second station. For the working up of the material, the author wishes to express his thanks for grants from "Kr. Birkelands fond til geofysisk forskning" and "Statens Forskningsfond".

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A. W. BRØGGERS BOKTRYKKERI A/S

Explanation to the Plate.

No. 1. Parallactic photographs of aurorae in west (Bootes) taken 27. 10. 1935 at $17^h16^m52^s$ MET, time of exposure 9 sec.

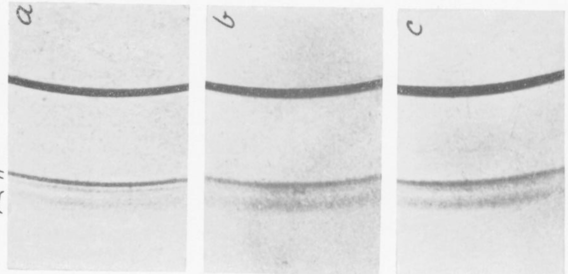
» 2, 3, 4 and 5. »Auroral clouds« photographed 28. 10. 1932 at $2^h51^m33^s$, $2^h52^m40^s$, $2^h53^m57^s$ and $2^h55^m15^s$ MET. Note the pulsation of the ray to the left — on 4 the ray has almost disappeared and on 5 the ray is returning to exactly the same place as on the previous photograph.

» 6. Four spectra taken 9. 2. 1935 at about 17^h10^m, 17^h35^m, 17^h58^m and 18^h08^m MET. The two first spectra are of sunlit draperies in the west, the two second, of aurorae lying in the shadow in east. Note the increase of 5577 Å (to the left in the spectra) relative to 3914 Å (to the right in the spectra) when going from the sunlit aurorae to aurorae lying in the shadow.

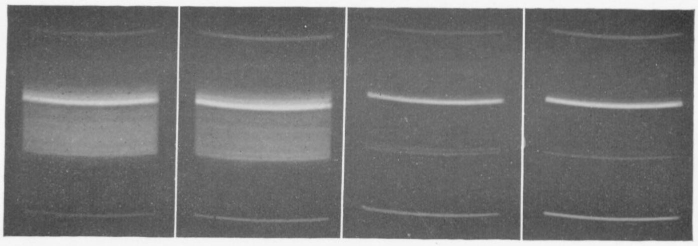
» 7. Three spectra in red and green of aurorae. *a* was exposed 16. 2. 1936 against arcs with a faint red lower border, *b* and *c* were exposed 17. 2. 1936 against normal yellow green arcs.

» 8. Partly sunlit ray photographed 24. 3. 1936 at 21^h16^m MET.

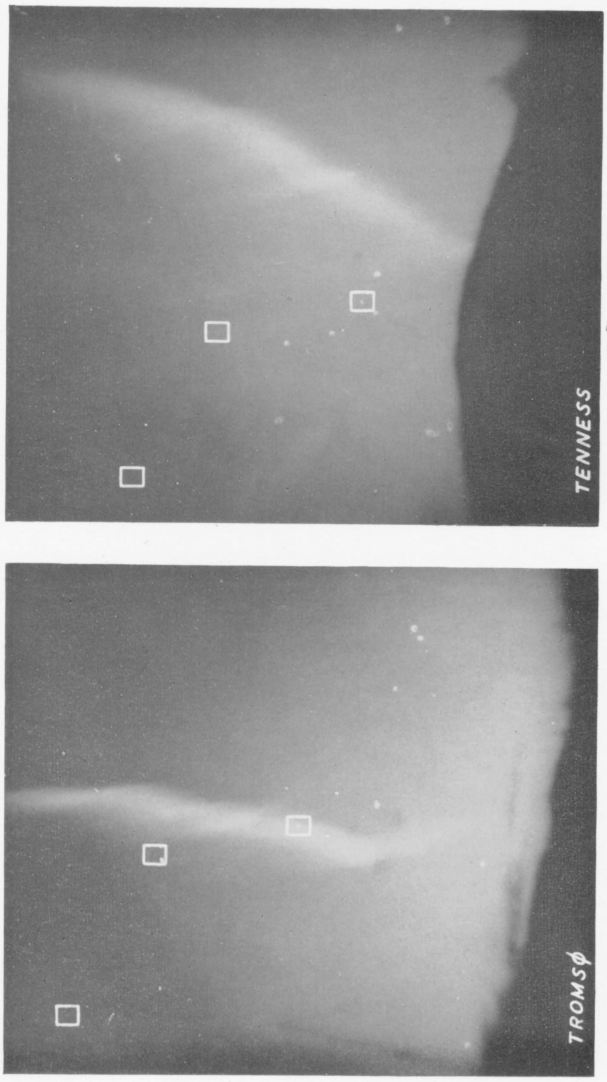
8



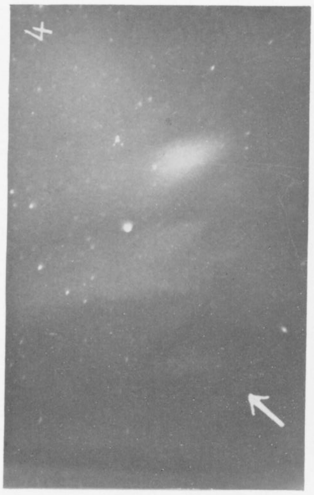
7



6



1



4

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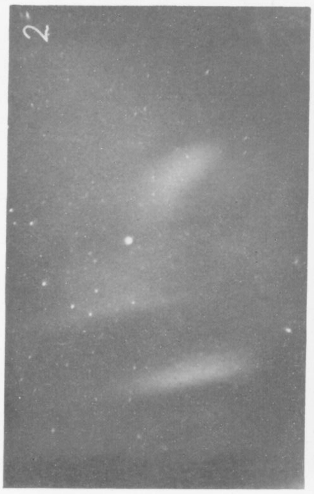

2

3

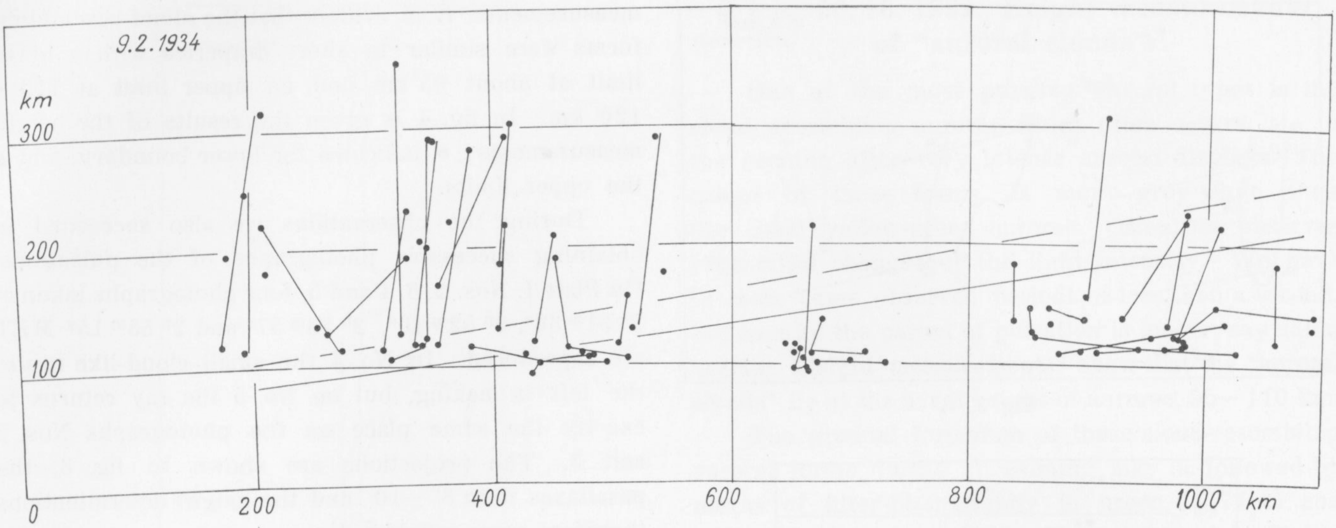

Fig. 5.

The angular height of the spectrograph during all four exposures was the same, the selective extinction is therefore the same on all spectra.

The densities of the spectra were measured out by a photo-electric microphotometer made at the observatory. Plate I No. 6 shows the spectra and fig. 6 the records. Although the slit of the spectrograph was narrow, the continuous light from the afternoon sky is strong on the two first spectra of the sunlit aurorae. From the records it is evident that on the first and second spectrum for the intensities of 5577 Å and 3914 Å we have: $^{I}5577 \leqq {}^{I}3914$, and on the two last spectra we have $^{I}5577 > {}^{I}3914$.

On a plate from the same stock, density marks by means of a Zeiss "Stufenfilter" were copied on, and developed in, the same standard developer. From this plate the intensity variation was determined quantitatively. In the following table we have put the intensity of 5577 as equal to 100 in each spectrum.

		$^{I}5577$	$^{I}3914$
Spectrum	1	100	112
»	2	100	100
»	3	100	67
»	4	100	69

The intensity variation thus confirms the observations of Størmer of the increase of the intensity of the nitrogen bands in the sunlit aurorae.

Later in the evening, between 23^{h} and 24^{h} 50 pairs of photographs were taken of usual green yellow aurorae. As these pictures are of the usual types, we will not give the results of the height determinations.

The earth-magnetic perturbation during the appearance of the sunlit aurorae was strong, in H a positive storm of 250—300 γ. Fig. 7 shows the earth-magnetic records during the auroral photography.

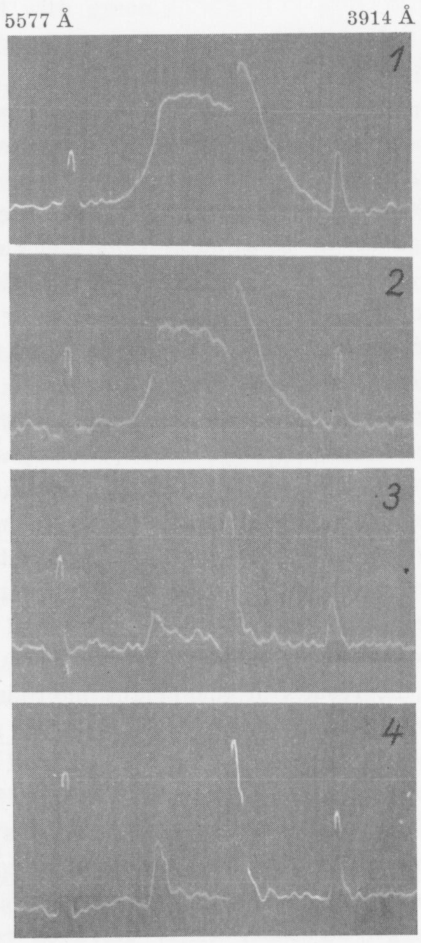

Fig. 6.

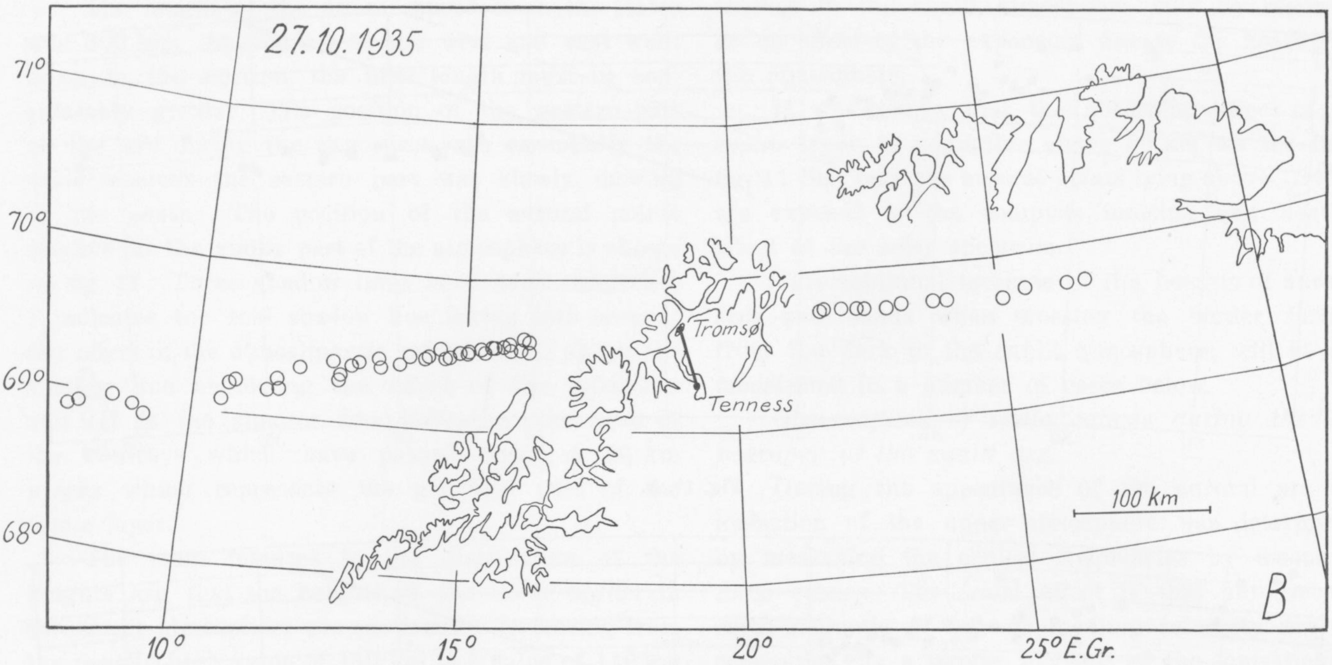

Fig. 12 B.

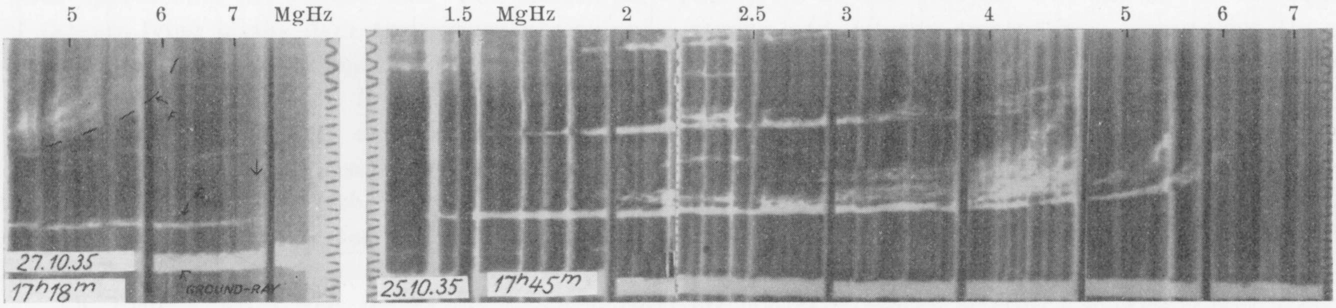

Fig. 13.

§ 3 f. 15. 2. 1936. Sunlit auroral Arc.

A faint, diffuse auroral arc of the usual green yellow colour appeared in the luminous afternoon sky about 35° above the horizon in the north at $17^h 20^m$ MET.

We succeeded in obtaining communication with Tenness during $17^h 25^m$—$17^h 32^m$ and 24 pairs of photographs were taken. On the photographs of the arc in the west and north the most intense stars in *Lyra-Cygnus* and *Ursa Major* could be traced out of the luminous background from the afternoon sky. On the plates of the eastern part of the arc in *Leo* it was impossible to trace out these less intense stars and the photographs had to be rejected.

From $17^h 32^m$ to $17^h 44^m$ communication with Tenness was broken, the sky meanwhile rapidly becoming covered by clouds. A new arc (III) appeared in the north and 12 pairs of photographs were taken

The following pictures conld be used for height determinations:

Table 4.

No.	MET	Time of Exposure	Constellation of Stars	
1	$17^h 25^m 32^s$	4 sec.	Lyra-Cygnus	I
2	51	8 »	U. Maj.	
3	57	4 »	»	
4	26 07	5 »	»	
5	30	4 »	Lyra-Draco	
6	27 58	11 »	Lyra-Draco	II
7	29 21	6 »	»	
8	57	4 »	U. Maj.	
9	44 42	11 »	U. Maj.-Bootes	III
10	50	5 »	»	
11	45 07	3 »	»	
12	15	6 »	»	
13	24	4 »	»	
14	46 30	3 »	»	
15	37	4 »	»	
16	44	5 »	»	