MEASURING OF AURORAE WITH VERY LONG BASE LINES

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1. Introduction.

Since 1911 I have had a series of photographic stations in action for measuring the height and situation of the Aurora Borealis over southern Norway. The detailed report[1] from the years 1911 to 1922 has been published in Geofysiske Publikasjoner Vol. IV, No. 7. Since 1923 a very great material of aurora photographs has been secured and short abstracts of the results obtained have been published from time to time.[2] A detailed report is in preparation.

An improvement in the equipment of the stations has been achieved since the polar year 1932—33. Six of the cameras with Erneman lenses have been replaced by standard cameras with Astro lenses of the type used during the polar year.

Further, great facilities have been obtained for the measurements and calculation of the plates. New projection cameras have been purchased from grants by "Det Videnskabelige Forskningsfond av 1919" and, last but not least, new convenient offices and laboratory-rooms have been secured in the new Institute for Theoretical Astrophysics, given to Norway by Rockefeller.

The photographic stations in action during the last few years have been the following:

Oslo, double station (*C*),
Oscarsborg (*O*),
Kongsberg (*K*),
Tømte (*T*),
Lillehammer (*Li*),
Løkken Verk (*Lø*),

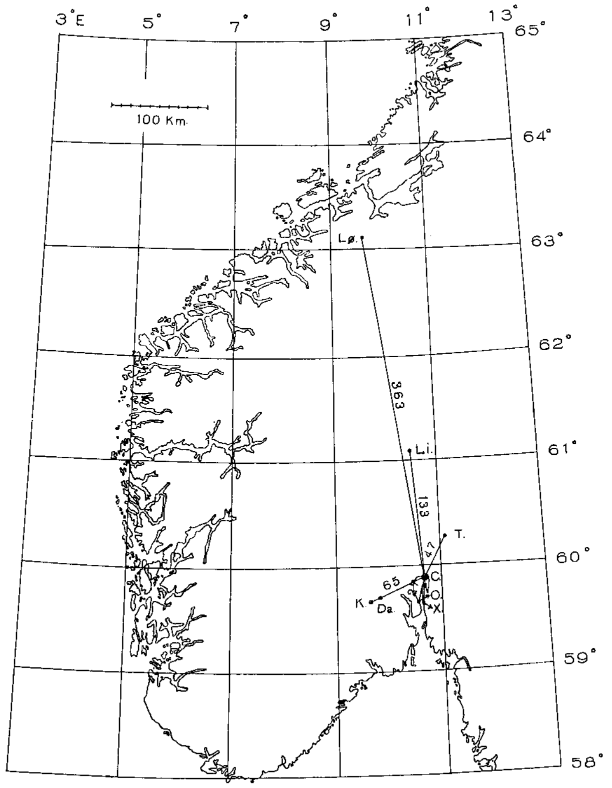


Fig. 1. Situation of aurora stations.

the situations of which are seen in Fig. 1. All these were provided with standard Astro-cameras, except (*Lø*) where a camera with Ernemann lens was used.

Moreover, I have a single station at Darbu (*Da*) near Kongsberg and a summer station Villa X (*X*) near Oscarsborg. At Darbu only single pictures are taken, because the principal of the station, Mr. Hassel, is deaf and dumb, but in spite of this he is one of my best observers and has sent me a great many excellent photographs not only of aurora, but also of nacreous clouds and luminous night clouds.

At the different aurora stations I have now a series of very able assistants who also telephone to

1 Carl Størmer: Résultats des mesures photogrammétriques des aurores boréales observées dans la Norvège méridionale de 1911 à 1922, Geof. Publ. l. c.

2 See in particular: Carl Størmer: Über die Probleme des Polarlichtes. Ergebnisse der kosmischen Physik, von Conrad und Weickmann, Akademische Verlagsgesellschaft, Leipzig 1931. Volume I.

me if they discover an aurora. By the courtesy of the Department of Telegraphs all the telephone lines connecting my stations are put at my disposal without cost as long as the aurora lasts. In clear weather, therefore, hardly any aurora escapes our attention.

The expenses for the maintenance of this useful net of aurora stations are included in the budget of "*The Norwegian Institute of Cosmical Physics.*"

From 1923 till now, photographic height measurements have been made on 77 nights and single photographs on 23 nights. The number of successful sets taken simultanously from 2, 3 or 4 stations amount to about 2000. To this must be added about 1250 successful single pictures.

Only a part of this extensive material is measured, but the work is now in good progress.

2. Measurement with very Long Base Lines.

For very diffuse aurora or for aurora low down to the horizon, the use of very long base lines is necessary if great accuracy is required. Already during the period 1911—1922, I had at my disposal the very long base line from Bygdøy to Dombaas, 258.52 km, but in 1934 I had on some occasions telephonic connection with the station Løkken Verk which together with the other stations gives still longer base lines. The longest was from Kongsberg to Løkken with base-length:

$$K\text{—}L\o = \text{about } 385 \text{ km.}$$

When simultaneous photographs are to be taken from two stations so far from each other, the two observers cannot point their cameras against the same stars because the parallax is too great. It is necessary to remember that the displacement of the aurora occurs along the great circle having the base line as a diameter and, moreover, by telephone to get approximate information of the position of the corresponding parts of the aurora.

Also when the plates are to be measured, each picture requires its own reference stars. It is, in general, not difficult to find corresponding points because the angle between the above-mentioned great circle and the vertical through the "base point" at the principal station can be calculated for each reference star. Necessary details will be given below.

3. The Aurora of August 27, 1934.

At $16^h 45^m$ Mid-European Time (MET) I was informed from the Department of Telegraphs that earth currents of 4 milliampères were observed on the line Oslo—Lillehammer. I therefore asked my assistant Tveter at Oslo Observatory to look for aurora in the evening. At $22^h 15^m$ he saw an arc in the north and I immediately warned my other stations. At $22^h 56^m$ telephonic connection between the stations Oslo, Lillehammer and Løkken Verk was established and the first simultaneous photographs could be taken. The station Kongsberg was connected to the others at $23^h 28^m$. Tømte was also warned, but at that station photographic work was prevented by clouds.

About 50 sets of simultaneous pictures were taken, and among these 20 sets from two stations and 15 from three, were successful. To these come 10 good single pictures, and from Hassel at Darbu 16 good single pictures of the same aurora.

I conducted the work myself from Oslo and had there as assistants Tveter, Anda, Miss Ording and a young man, Groth Hansen. At Kongsberg, Busengdal took the photographs, at Lillehammer, Ola Høstmælingen and at Løkken Verk, Captain Herstad. At Tømte, the assistants were Albert and Egil Tømte.

The aurora was of the ordinary type. As seen from Oslo it began as a homogenous arc low in the north. Of this arc were taken, from $22^h 57^m$ till $23^h 33^m$, 23 sets of pictures. At about $23^h 31^m$ short rays were seen near the star 12 Canis. venat., and on the picture taken $23^h 33^m 20^s$ the arc is seen to be dissolved in rays. The following 19 sets, from $23^h 34^m$ till $23^h 47^m$, were taken of rays along the same arc. Later, the aurora was very faint, but one set was taken at $0^h 35^m$ and 3 sets at $1^h 54^m$ till $1^h 58^m$. At 3^h the work ended.

4. The Simultaneous Photographs from Kongsberg and Løkken Verk.

The set which we have chosen as the representative one for sets with very long base lines, was taken at half past eleven at night. The exposure lasted 25^s and the time of the middle exposure was $23^h 29^m 17^s$ MET. The 3 stations, Oslo, Kongsberg and Løkken, exposed simultaneously and all 3 pictures were good. The aurora as seen from Oslo and Kongsberg had the form of an arc with a rather sharp lower boundary. That the upper border has the form of a half circle is only the effect of the dropping off of the luminosity of the lens towards the border of the picture. (Plate I, 1.) From Løkken Verk the arc was high up in the northern sky, over Ursa major, and the lower border was more irregular and showed a tendency to ray structure. This is in accordance with the later pictures, where the arc, as seen from Oslo, dissolved in rays two minutes later. The Løkken picture is seen on Plate I, 2.

As reference stars on the Kongsberg picture were chosen:

λ, ω and ψ Ursae Majoris.

These stars can easily be recognized on the negative, but can hardly be seen on the reproduction Plate I, 1; distorted traces, however, of the two stars β and γ Ursae Majoris are seen near the upper border of the picture.

As reference stars on the Løkken picture were chosen:

μ and ϑ Bootis and
ι Draconis.

Among these ϑ Bootis is seen on the reproduction, as well as the three stars ε, ζ and η of the Great Bear.

We have made two independent calculations, first with Kongsberg and then with Løkken, as main station.

5. The Results obtained with Kongsberg as main Station.

The following measurements and calculations have been made by one of my assistants, Mr. Håkon Anda. The method followed is the same as explained in earlier papers.[1] A short exposition of the method is given below:

By means of a lantern the negative is projected on a white sheet of paper, the enlargement being such that one degree of arc at the centre of the picture corresponds to 1 cm of the paper. With a pencil the star images and the outlines of the aurora are drawn on the paper for each of the corresponding negatives.

The drawings from a pair of simultaneous plates are next placed on a glass plate illuminated from below so that the drawing as well as a measuring net are seen simultaneously through the thin paper. By means of these nets, which will be explained later, the angles necessary for calculation can easily be measured with an accuracy of $0^\circ.1$. The computations involved are done by a calculating machine, or by a slide rule, combined with graphical methods.

[1] Størmer, Carl: Height and Velocity of luminous night-clouds observed in Norway 1932. Oslo University Observatory Publication No. 6, where references are found.

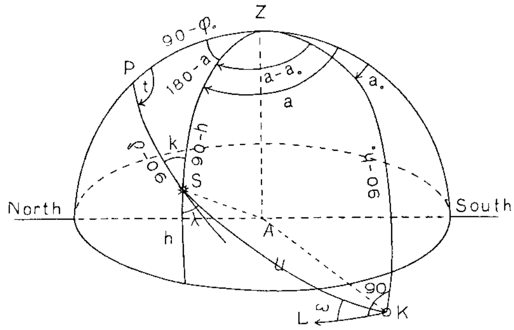


Fig. 2. The sky at the station A.

For the better understanding of the methods we shall give the necessary formulae. Suppose that we have two corresponding auroral stations, the main station A and the secondary station B. Let us consider the sky at *the main station* A. The base line AB cuts the sky at two points, the point K in the direction A to B, and the opposite point K' in the direction B to A. Let S be a star and let u be the angle between the direction AK and the direction AS. (See Fig. 2.)

Further, we shall call ω the angle between the plane AKS and a plane through AK normal to the vertical plane ZK through K. In a paper by Harang and Tønsberg[2] very convenient names have been introduced for K, K' u and ω: K and K' are called *base-poles*, u *base-distance* and ω *base-altitude*. The plane AKS is called *the plane of displacement*, because an auroral point N in the direction AS, when viewed from the secondary station B, will be displaced in this plane relative to its direction viewed from A.

The following formulae, well known from elementary spherical astronomy, follow at once from the diagram:

$$\sin h = \sin \varphi_0 \sin \delta + \cos \varphi_0 \cos \delta \cos t\,,$$
$$\sin a = \cos \delta \sin t \sec h\,,$$
$$\cos a = -\cos \varphi_0 \sin \delta \sec h + \sin \varphi_0 \cos \delta \cos t \sec h\,,$$
$$\sin k = \sin a \cos \varphi_0 \sec \delta = \sin t \cos \varphi_0 \sec h\,,$$

and further:

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

[2] Leiv Harang and Einar Tønsberg: Investigations of the Aurora Borealis at Nordlysobservatoriet Tromsø 1929—1930, Geof. Publ. Vol. IV, No. 5.

As a control we have:

$$\sin u \sin \lambda \quad \cos h_0 \sin (a - a_0)$$
$$\sin u \cos \lambda = -\sin h_0 \cos h + \cos h_0 \sin h \cos (a - a_0) .$$

Here the letters have the following meaning:

- φ_0 the geographical latitude of the station A,
- t the hour angle of the star, equal to the sidereal time at station A minus the right ascension of the star,
- δ the declination of the star,
- h the altitude of the star,
- a the azimuth of the star,
- u the base-distance of the star,
- ω the base-altitude of the star,
- k the angle between the great circles going from the star to the Zenith and to the pole P,
- λ the angle between the plane of displacement and the vertical plane,
- h_0 the height of the base-pole K,
- a_0 the azimuth of the base-pole K.

From the coordinates of the star, the coordinates of the main station and the time of observation, h, a and k are found; the coordinates of the second station then give u, ω and λ.

For each star used in the computations these angles are marked on the sketches, and the corresponding values of the same angles can then easily be read off for every selected point of the aurora, by means of suitable nets. Suppose circles of constant declination δ and constant right ascension to be drawn on a celestial sphere with interval of 2°; imagine a part of these intersecting curves to be photographed by the auroral camera and by means of the lantern projected on a wall so that one degree corresponds to one centimeter. The projected image of the intersecting curves will then be identical with the net used. In these nets the effects of the deformations due both to the photographic objective and the projecting lens are included. A very practical method of constructing such nets by taking a series of photographs of the same stars with an interval of 8 minutes and on the same plate, has been given by Harang and Tønsberg in their paper.

When the values of the angles u and ω have been found and controlled for an auroral point on both sketches, and when h and a are obtained from the sketch from the main station, the height and geographical situation of this point can be found as follows:

The distance r from station A to the auroral points is given by the formula:

$$r = g \frac{\sin u_2}{\sin p}, \quad \text{where } p = u_2 - u_1,$$

where g is the length of the base line and where u_1 and u_2 are the values of the angle u for the auroral point as seen from station A and station B; $p = u_2 - u_1$ is the parallax of this point; r is found either by a slide rule or by a calculating machine combined with tables of natural sines.[1] The height H above the earth's surface is found graphically by means of a vertical section through the earth's surface on the scale 1 : 1 000 000. The point (r, h) corresponding to the auroral point is marked on this section and the height is then easily measured by a steel millimeter ribbon. At the same time, the distance D from the station A along the earth's surface to the vertical projection of the auroral point is measured, which together with the azimuth measured on the sketch, gives the geographical situation of the auroral point.

For the base-line *K-Lø* Anda has found

$$a_0 = 180^\circ.24,$$
$$h_0 = -1^\circ.71,$$
$$g_0 = 385.075 \text{ km},$$

[1] For instance: Tafeln für numerisches Rechnen mit Maschinen, herausgegeben von O. Lohse, zweite Auflage, Leipzig 1935.

Star	t	h	k	a	u	ω	λ
ψ Urs. maj.	180°—24.1	16.4	12.4	180—17.5	25.2	180—46.5	360—45.8
ω » »	180°—20.1	14.5	10.3	180—14.9	22.1	180—47.7	360—44.0
λ » »	180°—10.8	13.3	5.6	180— 8.1	17.1	180—61.4	360—29.5
μ Bootes	180°—88.1	30.9	36.0	180—67.3	71.8	180—33.4	360—76.5
ϑ »	180°—73.3	36.3	36.9	180—46.8	57.9	180—45.9	360—59.7
ι Drac.	180°—88.4	47.2	48.0	180—48.9	65.1	180—55.5	360—56.5

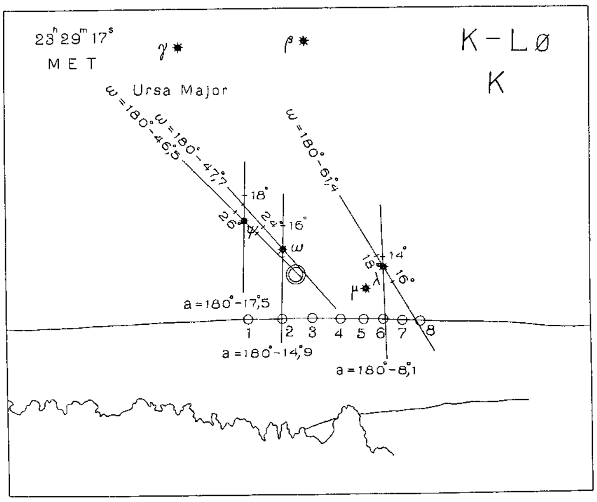


Fig. 3. Sketch made from the Kongsberg picture with *Kongsberg* as main station.

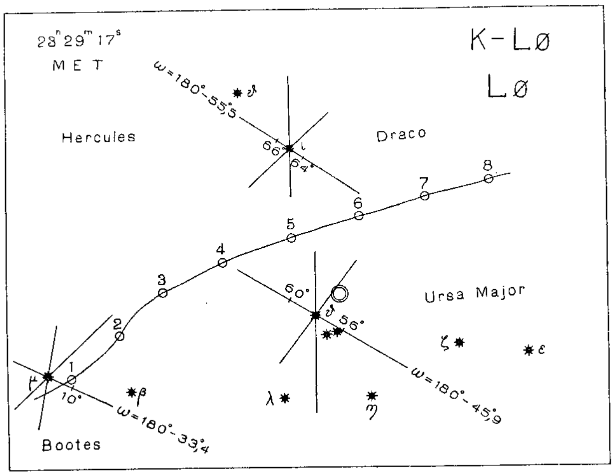


Fig. 4. Sketch made from the Løkken picture with *Kongsberg* as main station.

and this gives for the reference stars the corresponding values of the t, h, k, a, ω and λ at the main station in tenths of degrees.[1] (See table p. 6.)

These values were plotted on the sketches made from the negatives and by means of the nets the values of the same angles were found for a series of auroral points on the Kongsberg picture. (See Fig. 3.)

The corresponding points on the Løkken picture having the same ω-values as those on the Kongsberg picture, were found by means of the nets and from these the parallax was measured. The results are given in the table below.

The height of the different points along the lower border is lower than the mean 110 km for homogeneous arcs which is explained by the fact that the arc was about to dissolve into rays. From Kongsberg this could not be seen but at Løkken the ray-structure is already visible.

[1] The calculation was made in hundredths of degrees.

6. The results obtained with Løkken as main Station.

As a control we have also made the same calculation with Løkken as main station. For the stars we get the values given in the table p. 8.

In Fig. 5 and 6 the sketches are seen.

This gave the results seen in table p. 8 below.

The agreement between the heights in the two cases is as perfect as can be expected by graphical methods.

Another test is to plot the projection of the auroral points on the earth's surface. This has been done and the situations of the arc are seen to fall close to each other. (See Fig. 7.)

Aurora August 27, 1934, $23^h\ 19^m\ 17^s$ MET. Base Line K—Lø.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	20.8	70.3	49.5	475	180—34	9.9	180—17.1	98.0	463
2	19.2	68.8	49.6	471	180—38	10.0	180—14.9	98.0	459
3	17.7	67.5	49.8	465	180—42	10.0	180—12.8	97.0	453
4	16.3	65.0	48.7	464	180—46	10.0	180—11.0	97.0	452
5	15.3	61.9	46.6	467	180—50	10.0	180— 9.5	97.5	455
6	14.4	58.9	44.5	470	180—54	9.9	180— 8.2	97.5	459
7	13.7	56.2	42.5	474	180—58	9.9	180— 6.9	98.0	462
8	13.0	53.6	40.6	475	180—62	9.8	180— 5.8	98.0	463

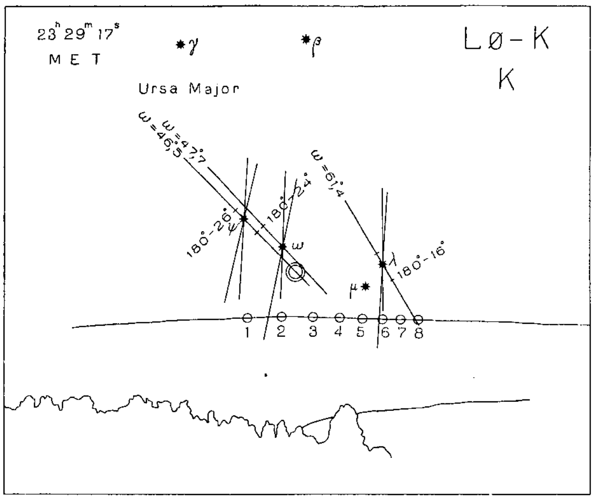


Fig. 5. Sketch made from the Kongsberg picture with *Løkken* as main station.

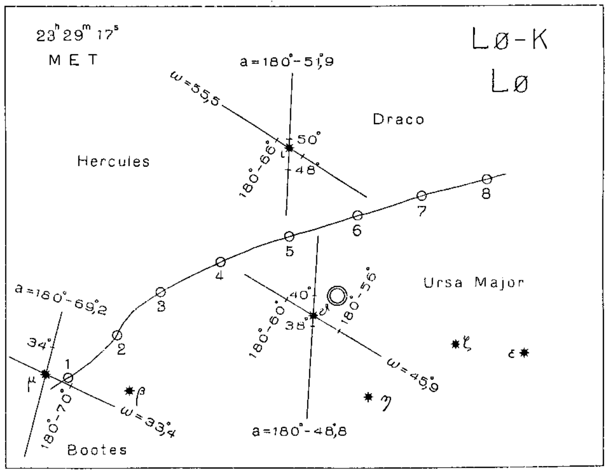


Fig. 6. Sketch made from the Løkken picture with *Løkken* as main station.

Star	t	h	k	a	u	ω	λ
ψ Ursae maj.	180—24.0	19.7	11.3	180—17.8	180—25.2	46.5	180—46.9
ω » »	180—20 1	17.9	9.4	180—15.2	180—22.1	47.7	180—45.0
λ » »	180—10.8	16.7	5.1	180— 8.2	180—17.1	61.4	180—30.0
μ Bootis	180—88.0	32.1	32.2	180—69.2	180—71.8	33.4	180—80.2
ϑ »	180—73.3	38.6	33.7	180—48.8	180—58.0	45.9	180—63.0
ι Drac.	180—88.4	49.4	44.0	180—51.9	180—65.1	55.5	180—60.6

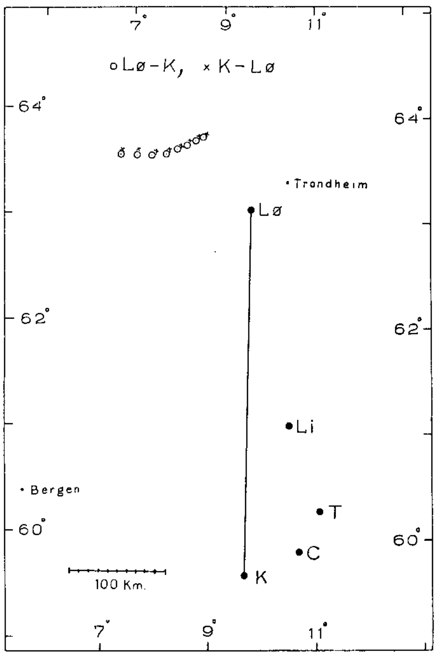


Fig. 7. Situation of lower border of the auroral arc as measured with base lines *K—Lø* and *Lø—K*.

The same Aurora August 27, 1934, 23h 39m 17s MET. Base Line Lø—K.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	180—70.3	180—20.8	49.5	179.0	34	32.3	180—67.3	98.0	150
2	180—68.8	180—19.2	49.6	166.0	38	35.7	180—64.5	98.5	134
3	180—67.5	180—17.7	49.8	153.5	42	39.0	180—61.7	98.0	119
4	180—65.0	180—16.3	48.7	144.0	46	41.7	180—57.0	97.0	107
5	180—61.9	180—15.3	46.6	140.0	50	43.7	180—51.2	98.0	101
6	180—58.9	180—14.4	44.5	137.0	54	45.2	180—45.0	98.0	96
7	180—56.2	180—13.7	42.5	135.0	58	46.3	180—39.0	98.5	93
8	180—53.6	180—13.0	40.6	133.0	62	46.9	180—33.0	98.0	91

7. The Aurora on January 27, 1935.

This aurora was of an average size and did not reach the zenith in Oslo. But it was observed and photographed under the most favourable conditions and gave very interesting results.

My assistent Høstmælingen at Lillehammer was the first who telephoned to me and said that he saw three aurora arcs in the north: the lowest near the horizon, the second passing through Deneb and the upper one through Cassiopeia and the stars ε, η, ζ Ursae majoris. It was then 20^h MET.

I immediately warned my aurora stations Oscarsborg, Kongsberg and Tømte. I am sorry to say that the station Løkken Verk was out of function because my excellent assistant Captain Herstad was seriously ill.[1]

A little before 21^h I got the stations in order and we worked all night till 6^h in the morning and took many hundreds of photographs simultaneously from 2, 3 and 4 stations and also a great many single ones; independently of us, Hassel took also a great many single photographs from his station Darbu.

Among these the following were successful:

119 single photographs			
87	sets simultaneously from	2	stations
29	—»—	3	—
26	—»—	4	—

Of this most valuable material we shall later give the results of a few of special interest.

At the station Oslo I conducted the work myself and took 12 sets of photographs. Later the photographic work was undertaken by Tveter and Anda and as assistants were Leiv Rosseland, Herlofson and my youngest son Fredrik. Two Astro-cameras were in action and a series of very successful pictures was also taken with a small Leika camera F 2 with Superpan film. *For future expeditions it is important to know that it is possible to photograph the aurora with Leika and Superpan film*, because this is much easier to handle and requires much less room than Astro-cameras and plates.

At Oscarsborg, Tømte, Kongsberg and Lillehammer, my assistants were Bakøy, Albert and Egil Tømte, Busengdal and Høstmælingen, all very able and accustomed to the work.

As to the aurora itself and its development as seen from Oslo, the following account may be of interest:

When the photographic work began at $20^h 58^m$, there was an aurora arc near the horizon under Cygnus and a second very diffuse and pulsating one from Pegasus in the West up to the Great Bear. Of this second arc we took 12 successful sets of pictures some of which will be mentioned later. This arc disappeared about $21^h 18^m$.

Of the lower arc a long series of pictures was taken during the hours following. Sometimes very fine distant curtains were seen under the arc and many sets were taken of them. But it was not until after midnight that the most interesting display began. The arc rose higher and began to show ray structure. A fine series of this development was taken about 1^h. A little before half past one a fine distant yellow-green curtain was seen under the arc in the north. A preliminary measurement showed that the lower border was situated over the town Namsos at an altitude of 101 to 103 km.

From $1^h 32^m$ the lower border of the arc grew successively sharper and brighter and changed at $1^h 51^m$ to beautiful multi-coloured curtains which developed with great rapidity from the west towards north-east. The rays were red at the lower border and on the front side of the motion. Of this splendid display a great many sets were taken, one of which will be mentioned later. This fine display ended at 2^h and there remained only diffuse cloud-like aurora patches of which some sets of pictures were taken.

The aurora then died down more and more, but the stations kept watch until 6^h, when I gave orders to cease work.

We shall now give the results of the measurements and calculations of some of these interesting aurora forms taken simultaneously with the long base lines *K—T*, *T—Li*, *K—Li* and *C—Li*.

8. The Pulsating Arc at $20^h 59^m 48^s$ MET.

This was photographed simultaneously from the 4 stations Oslo, Kongsberg, Tømte and Lillehammer. Exposure 45^s. The arc was situated in the west in the direction of Pegasus, and on account of the long exposure a great many stars are seen on the pictures. Plate I: 3, 4, 5 and 6 show a rather diffuse arc, but this does not come from the long exposure, but from the arc itself, which was without distinct borders. When making the sketches from the negatives, special care was taken to draw the lines where the borders had the same relative intensity.

We have made independent measurements of the same points of the aurora arc using the 4 base lines and the following reference stars:

[1] This illness has prevented him from continuing the work and the station has now been removed to the Physical Institute in Trondheim. I take this opportunity of thanking Captain Herstad for his excellent work.

	g	h_0	a_0	Picture	Stars	Plate
K—T.........	104.936 km	—0°.40	180 + 47.98	C	β, η Pegasi, τ Cygni	I, 5
T—Li	94.51 »	—0°.39	180—18.79	K	λ, β, η, π Pegasi	I, 6
C—Li	132.667 »	—0°.46	180— 5.13	T	α, β, η Pegasi	I, 4
K—Li	165.351 »	—0°.68	180 + 15.97	Li	α, δ Andromedae, λ Pegasi	I, 3

See Figs. 8, 9, 10, 11, 12 and Plate I: 3, 4, 5, 6.

We do not give here the values of the angles for these stars corresponding to different base lines. The results of the measurements were:

Arc at 20h 59m 48s MET. Base Line K—T.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	180—58.7	180—48.3	10.4	433	180—14.7	13.0	180—74.0	111	417
2	180—64.5	180—51.8	12.7	374	180—17.3	15.9	180—68.5	112	355
3	180—70.5	180—55.4	15.1	330	180—19.7	18.7	180—62.7	112	308

The same arc. Base Line T—Li.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	65.2	76.0	10.8	490	180—12.0	10.6	180—83.5	109.0	476
2	62.6	74.8	12.2	430	180—15.3	13.3	180—80.4	112.0	413
3	59.7	74.0	14.3	367	180—18.6	15.8	180—76.9	110.0	348
4	56.5	72.8	16.3	322	180—22.4	18.3	180—72.9	109.0	302
5	65.4	76.2	10.8	490	180—12.6	11.2	180—83.6	112.5	474
6	62.8	76.2	13.4	397	180—17.7	15.5	180—80.2	117.0	377
7	60.1	76.2	16.1	331	180—22.7	19.5	180—76.7	117.5	308
8	57.2	76.2	19.0	283	180—27.9	22.9	180—72.5	115.5	258
9	66.0	77.2	11.2	473	180—13.3	11.8	180—84.2	114.0	457

The same arc. Base Line C—Li.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	73.6	89.8	16.2	475	180—11.9	11.0	180—78.5	108.0	460
2	70.2	88.4	18.2	424	180—14.8	13.5	180—74.7	111.5	408
3	65.9	87.2	21.3	365	180—18.0	16.0	180—69.9	110.0	346
4	61.5	85.7	24.2	323	180—21.2	18.2	180—64.7	108.5	303
5	73.8	90.0	16.2	475	180—12.4	11.4	180—78.7	111.0	460
6	69.9	89.5	19.6	395	180—17.3	15.9	180—74.0	119.0	375
7	64.8	88.9	24.1	325	180—22.2	19.8	180—68.0	118.0	302
8	59.8	88.4	28.6	277	180—27.0	22.8	180—61.7	114.0	253
9	74.0	180—89.1	16.9	455	180—13.1	12.1	180—79.0	111.0	439

The same arc. Base Line K—Li.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	180—89.8	180—68.6	21.2	425	180—13.0	13.0	180—74.0	110.0	410
2	84.9	180—70.2	24.9	371	180—16.0	15.9	180—68.5	111.0	352
3	79.5	180—71.8	28.7	326	180—19.3	18.7	180—62.7	111.5	305
4	74.0	180—73.8	32.2	290	180—22.3	21.4	180—57.0	110.5	267

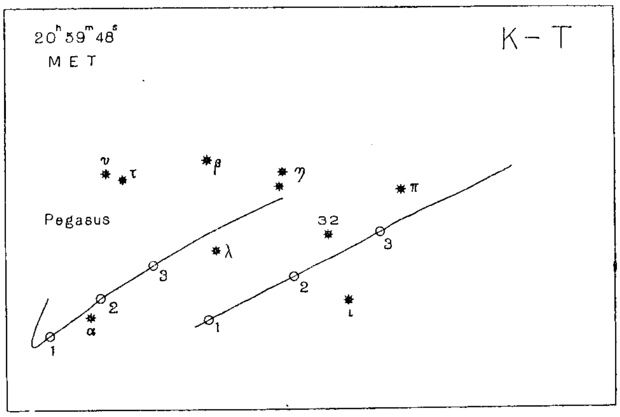


Fig. 8. Situation of the arc as seen from *K* (right) and *T* (left).

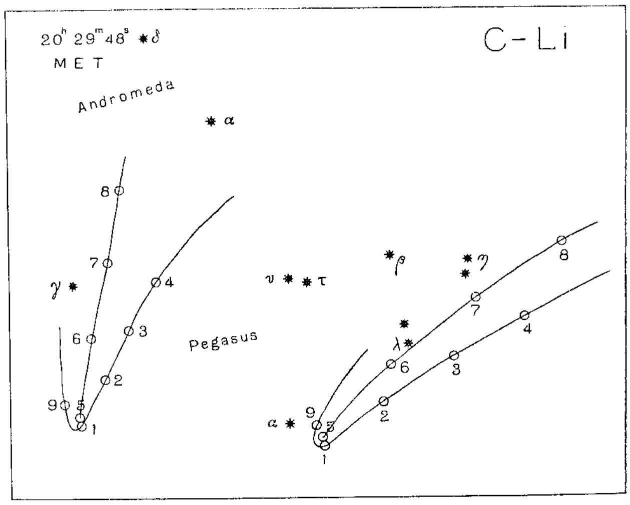


Fig. 10. Situation of the arc, seen from *C* (right) and *Li* (left).

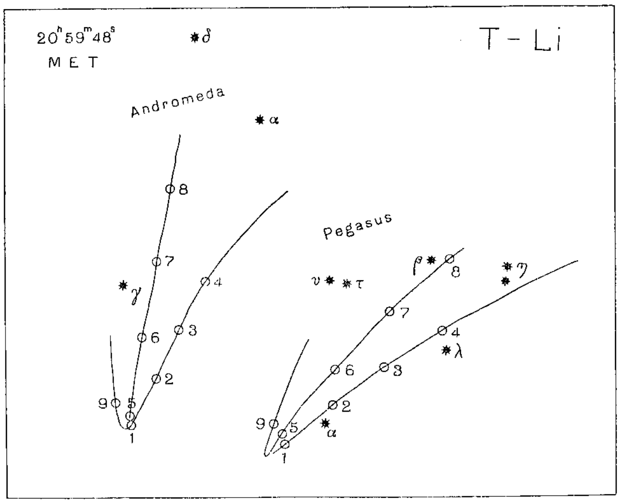


Fig. 9. Situation of the arc, seen from *T* (right) and *Li* (left).

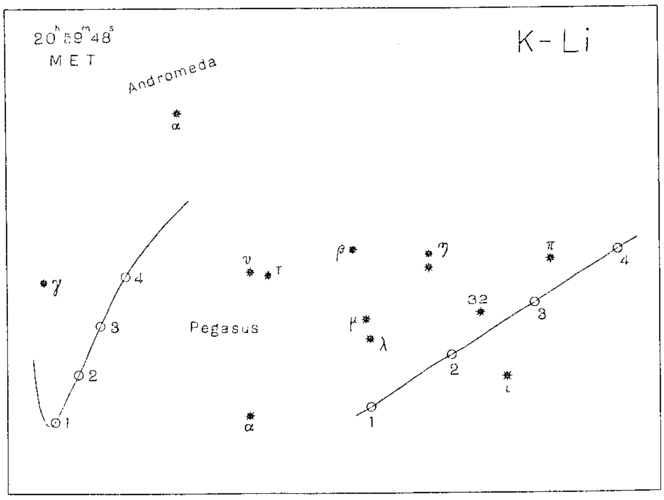


Fig. 11. Situation of the arc, seen from *K* (right) and *Li* (left).

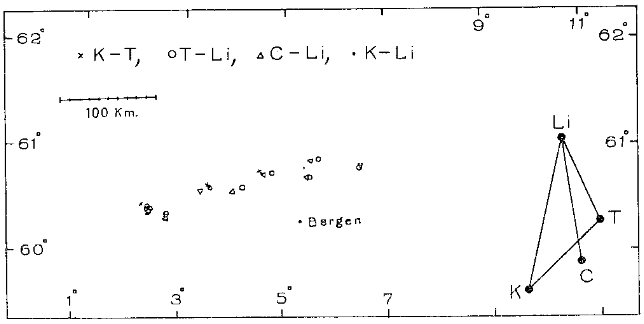


Fig. 12. Geographical situation of the arc.

As can be seen from these measurements the deviations from the mean for the first 4 points, in kilometers, are:

Point	*K—T*	*T—Li*	*C—Li*	*K—Li*
1	1.5	—0.5	—1.5	0.5
2	0.4	0.4	—0.1	—0.6
3	1.1	—0.9	—0.9	0.6
4		—0.3	—0.8	1.2

The points 5, 6, 7, 8 are chosen along the line of greatest intensity and 1, 2, 3, 4 along the lower border.

On the whole, the deviation is of the order of one to two per cent of the height, a very good result for such a diffuse aurora form.

The geographical situations of the arc for the different base lines are seen in Fig. 12.

The measured arc is a typical one for the case where a so-called "space-effect" had to be expected. This effect should come from the difficulty of fixing the same border of the arc when looking at it from two different places. In fact, the part of the air where the arc is situated is transparent and the luminosity depends on the thickness of the luminous air in the direction of sight so that each observer should have his personal impression of where the borders of the arc were situated. This was earlier a serious objection against the reliability of all height measurements of aurora.

From the case of the arc here measured, however, it is clear that with base lines of the order of 100 km and conveniently situated aurora, this objection has no practical importance.

9. The same Arc at $21^h 11^m 25^s$ MET.

It is also of great interest to mention a later picture of the same arc. This time no picture was taken in Oslo, but 3 good simultaneous pictures were secured at the other stations, Kongsberg, Tømte and Lillehammer. See Plate II: 1, 2, 3.

The arc was still very diffuse and had a remarkable irregularity near the lower end. The exposure lasted one minute.

As reference stars were chosen:

Picture	Stars	Plate
K	τ, γ, η Pegasi	II, 3
T	$\alpha, \beta, \lambda, \tau$ Pegasi	II, 2
Li	δ Pisces, γ Pegasi, η Andromedae	II, 1

The results of the measurements were:

Arc at $21^h 11^m 25^s$ MET. Base line K—T.

Point	u_1	u_2	p	r	ω	h	a	H	D
2	180—73.1	180—55.4	17.7	283	180—26.0	25.1	180—60.6	125.0	253
3	180—68.3	180—53.2	15.1	322	180—21.5	20.1	180—65.0	117.5	299
4	180—65.4	180—51.3	14.1	335	180—19.0	17.5	180—67.7	109.5	316
5	180—62.6	180—49.2	13.4	342	180—19.4	17.5	180—70.6	111.0	321
6	180—59.3	180—47.2	12.1	368	180—18.8	16.4	180—73.9	114.0	348
7	180—55.6	180—45.7	9.9	437	180—15.7	13.4	180—77.1	115.0	420
8	180—54.4	189—44.0	10.4	404	180—17.3	14.5	180—78.6	112.5	386
9	180—55.9	180—44.4	11.5	370	180—21.9	18.2	180—78.0	125.0	346
10	180—58.1	180—45.8	12.3	352	180—26.9	22.7	180—76.7	144.0	319

Same arc. Base Line T—Li.

Point	u_1	u_2	p	r	ω	h	a	H	D
2	62.2	79.2	17.0	317	180—23.9	20.8	180—78.7	120	292
3	62.5	77.2	14.7	363	180—19.5	16.8	180—79.8	115	342
4	63.7	77.5	13.8	387	180—16.4	14.5	180—81.3	109	370
5	65.6	78.9	13.3	403	180—15.9	14.3	180—83.4	112	385
6	67.5	79.8	12.3	436	180—14.7	13.5	180—85.5	116	418
7	68.2	79.7	11.5	467	180—11.8	10.9	180—86.4	105	454
8	70.0	81.0	11.0	488	180—12.5	11.6	180—88.3	115	471
9	70.6	82.6	12.0	450	180—15.8	14.7	180—88.7	130	429
10	70.8	84.3	13.5	407	180—19.8	18.5	180—88.5	141	380

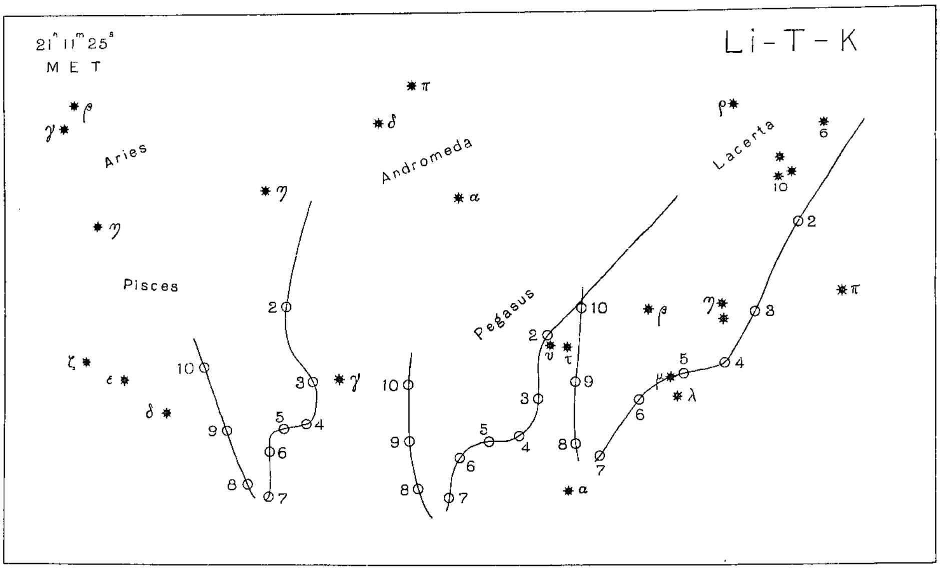


Fig. 13. Situation of the arc among the stars as seen from *Li* (left), *T* (middle) and *K* (right).

Same arc. Base Line K—Li.

Point	u_1	u_2	p	r	ω	h	a	H	D
2	78.3	180—68.2	33.5	279	180—26.0	25.1	180—60.6	124	249
3	81.9	180—69.1	29.0	319	180—20.6	20.1	180—65.0	117	295
4	84.2	180—68.3	27.5	333	180—17.7	17.5	180—67.7	109	314
5	87.0	180—66.8	26.2	343	180—17.5	17.5	180—70.6	111	323
6	90.0	180—65.7	24.3	365	180—16.2	16.4	180—73.9	113	345
7	180—86.9	180—65.6	21.3	417	180—13.1	13.4	180—77.1	110	401
8	180—85.5	180—64.2	21.3	412	180—14.1	14.5	180—78.6	115	394
9	180—86.1	180—63.1	23.0	377	180—18.0	18.2	180—78.0	128	352
10	180—87.2	180—62.2	25.0	347	180—22.7	22.7	180—76.7	142	315

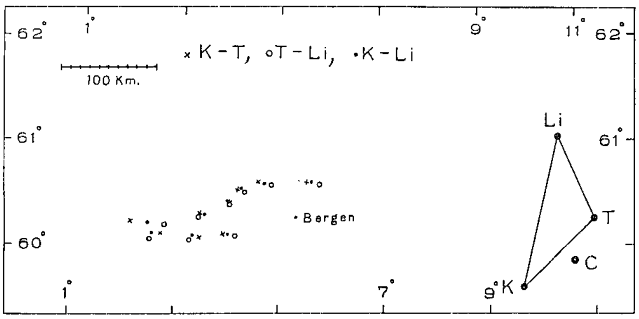


Fig. 14. Geographical situation.

The three sketches are combined in Fig. 13; Fig. 14 gives the situation according to measurements with 3 base lines.

If we compare these results with the reproduced photographs of the arc, Plate II: 1, 2, 3 we see that the greatest uncertainty occurs for the point 7, where the outline of the arc is so diffuse that it is very difficult to measure it. For this point the results from the longest base line *K—Li* are probably the most reliable.

10. Measurements of the Aurora Curtain at 1h 51m 28s.

Finally, we shall give the measurements with the base lines *K—T*, *T—Li* and *K—Li* of the splendid aurora curtain at 1h 51m 28s which represented the maximum of the auroral activity that night. The photographs were taken by telephonic signals from my assistant Anda who stood in connection with the stations *K*, *T* and *Li* at the same time. I was following the work and had just given orders to remove the camera in Oslo to a better place on the roof of the observatory, for which reason no picture was taken at Oslo simultaneously with the other three.

The exposure lasted 5 seconds. Among the stars, the Pleiades are seen in the reproduction and a series of other stars was easily found on the negatives. See Plate II: 4, 5, 6.

As reference stars were chosen:

Station	Stars	Plate
K	η Tauri, c, 35 Arietis	II, 6
T	α, η, λ Tauri	II, 5
Li	α, η, τ Tauri	II, 4

The results of the measurements were:

Curtain at $1^h\ 51^m\ 28^s$. Base Line K—T.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	180—61.5	180—52.2	9.3	515	180—11.3	10.2	180—70.9	111	501
2	180—63.3	180—53.0	10.3	470	180—13.1	11.9	180—69.3	113	454
3	180—66.2	180—54.3	11.9	413	180—14.4	13.4	180—66.3	109	397
4	180—68.6	180—57.2	11.4	443	180—11.6	11.0	180—63.6	99	430
5	180—67.7	180—56.3	11.4	440	180—18.4	17.1	180—65.3	144	414
6	180—69.9	180—58.4	11.5	446	180—11.0	10.5	180—62.3	96	434
7	180—68.7	180—57.4	11.3	450	180—18.2	17.0	180—64.2	147	422
8	180—71.5	180—61.4	10.1	525	180— 8.4	8.3	180—60.5	96	515
9	180—70.9	180—60.8	10.1	523	180—12.3	11.9	180—61.5	128	504
10	180—72.2	180—62.2	10.0	534	180— 7.9	7.9	180—59.8	95	522
11	180—71.8	180—61.9	9.9	537	180—12.7	12.3	180—60.6	135	517
12	180—73.3	130—59.7	13.6	386	180—16.9	16.3	180—59.3	120	365
13	180—75.4	180—61.3	14.1	378	180—17.1	16.6	180—57.2	119	357
14	180—75.3	180—61.2	14.1	378	180—14.0	13.8	180—57.0	100	362
15	180—73.8	180—60.1	13.7	385	180—13.7	13.4	180—58.5	100	370.5

Same Curtain. Base Line T—Li.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	61.0	69.7	8.7	587	180—10.2	8.7	180—79.1	114	572
2	60.3	70.0	9.7	528	180—12.0	10.3	180—78.4	115	513
3	59.5	70.0	10.5	488	180—13.5	11.4	180—77.4	113	472
4	56.0	66.5	10.5	476	180—11.7	9.6	180—74.1	96	464
5	58.6	69.0	10.4	488	180—17.8	15.0	180—76.0	143	462
6	54.8	65.0	10.2	482	180—11.5	9.2	180—72.8	95	471
7	57.5	67.8	10.3	488	180—18.0	15.0	180—74.8	143	462
8	51.3	59.5	8.2	570	180— 9.5	7.3	180—69.5	96	560
9	52.8	61.1	8.3	572	180—13.7	10.7	180—70.7	130	554
10	50.4	58.4	8.0	577	180— 9.1	6.9	180—68.6	94	567
11	51.8	59.9	8.1	580	180—14.4	11.1	180—69.5	137	560

Same Curtain. Base Line K—Li.

Point	u_1	u_2	p	r	ω	h	a	H	D
1	87.1	180—74.9	18.0	515	180—10.2	10.2	180—70.9	111	501
2	85.6	180—74.7	19.7	472	180—12.0	11.9	180—69.3	114	456
3	82.6	180—75.1	22.3	422	180—13.6	13.4	180—66.3	111	405
4	80.0	180—78.3	21.7	437	180—11.3	11.0	180—63.6	97	425
5	81.8	180—76.8	21.4	440	180—17.4	17.1	180—65.3	144	414
6	78.7	180—79.8	21.5	444	180—10.9	10.5	180—62.3	95	432
7	80.8	180—78.0	21.2	447	180—17.4	17.0	180—64.2	145	420
8	76.7	180—85.0	18.3	525	180— 8.7	8.3	180—60.5	96	514
9	77.9	180—83.9	18.2	525	180—12.3	11.9	180—61.5	129	506
10	76.0	180—86.0	18.0	532	180— 8.2	7.9	180—59.8	95	522
11	77.0	180—85.2	17.8	537	180—12.8	12.3	180—60.6	135	517

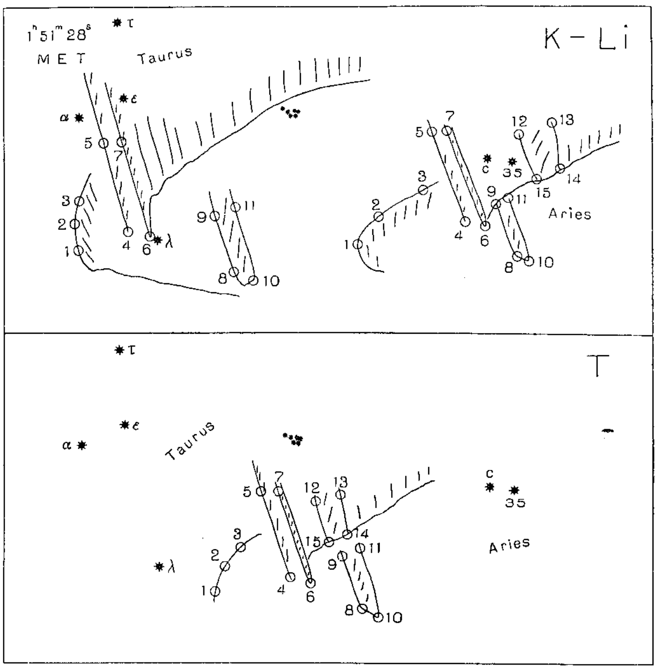


Fig. 15. Situation of the curtain among the stars as seen from *Li* (left), *T* (middle) and *K* (right).

The situation among the stars is seen in Fig. 15. See also Plate II.

In order to eliminate the possible errors from the graphical determination of height from p, u_2, r and h, we have as test calculated H directly by the formula developed in a paper which I published in 1911.[1] The results for the best measurements were (see tab.).

Here $\triangle (K—T)$ etc., means the height measured with base line $K—T$ minus the mean of the heights from the 3 base lines.

In Fig. 16 is seen the geographical situation of the curtain from the measurements with the 3 base lines $K—T$, $T—Li$ and $K—Li$.

[1] Carl Størmer: Bericht über eine Expedition nach Bossekop etc. Vid.-Selsk. Skrifter, Christiania (Oslo) 1911.

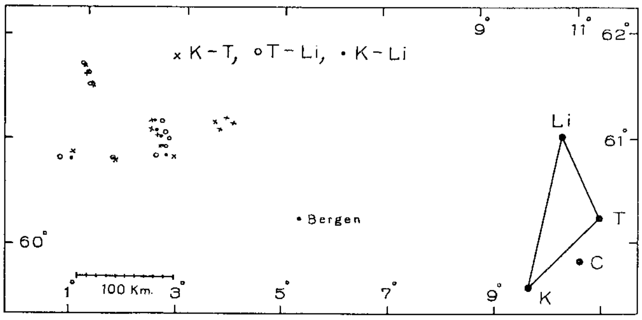


Fig. 16. Geographical situation.

Heights.

Point	$K—T$	$T—Li$	$K—Li$	Mean	$\Delta (K—T)$	$\Delta (T—Li)$	$\Delta (K—Li)$
5	143.5	143.6	143.3	143.5	0	0.1	—0.2
6	96.7	95.0	95.6	95.8	0.9	—0.8	—0.2
7	146.2	143.8	144.8	144.9	1.3	—1.1	—0.1
8	96.7	97.4	96.6	96.9	—0.2	0.5	—0.3
9	127.8	130.8	128.9	129.2	—1.4	1.6	—0.3
10	95.1	95.0	95.0	95.0	0.1	0	0
11	135.9	136.6	136.1	136.2	—0.3	0.4	—0.1

11. Conclusions.

It is seen from the photographs taken that, primarily, the use of very long base lines can give exact measurements even for aurora forms with badly defined outlines such as very diffuse arcs and patches. For well defined aurora forms the error in the measurements with such long base lines can be less than one hundredth of the height.

The case of the pulsating and very diffuse arc, photographed on January 27th, 1935, teaches that for base lines of the order of 100 km the so-called "space effect" has no practical influence on the height measurements.

Printed May 18th, 1935.

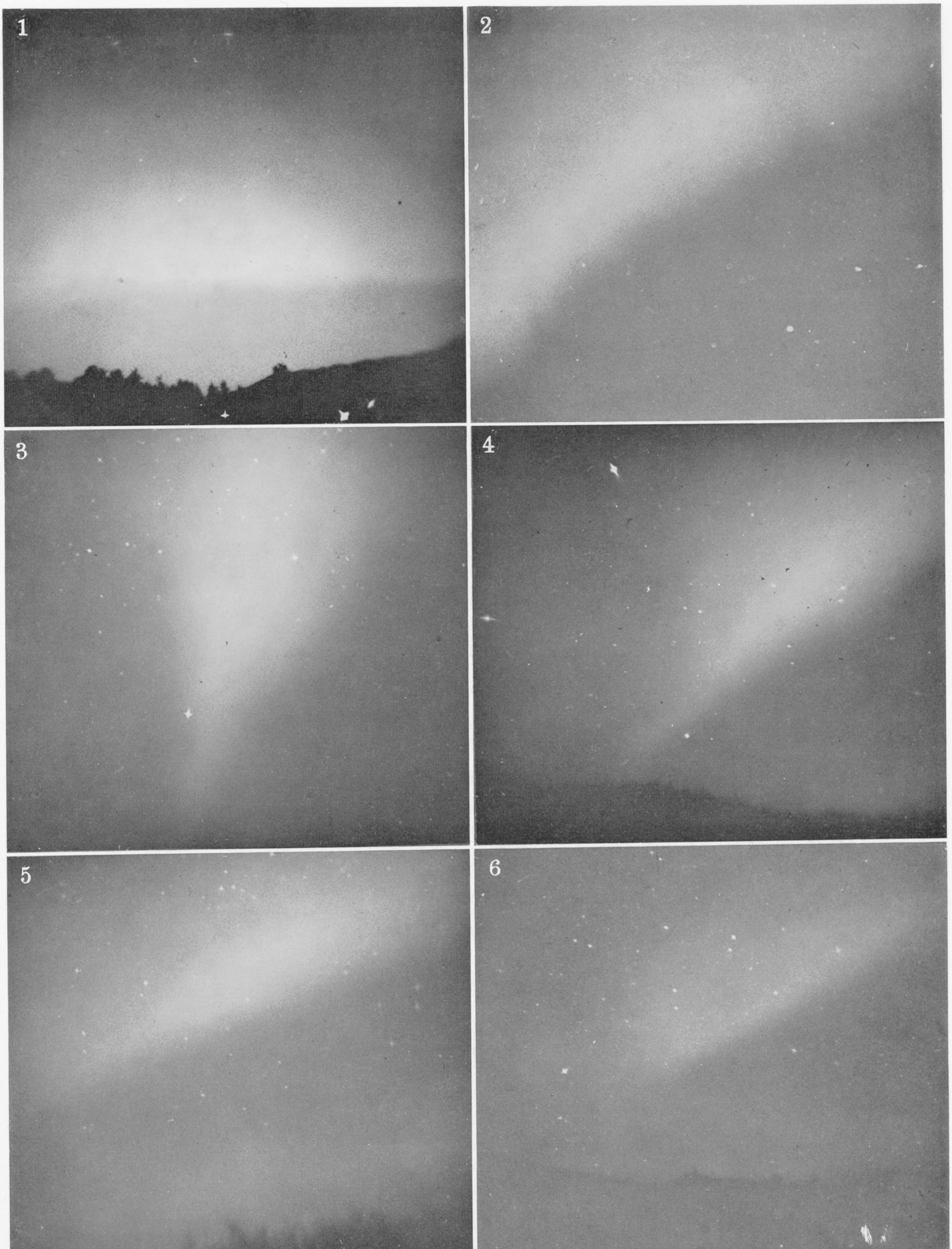
Explanation of the Plates.

Plate I:

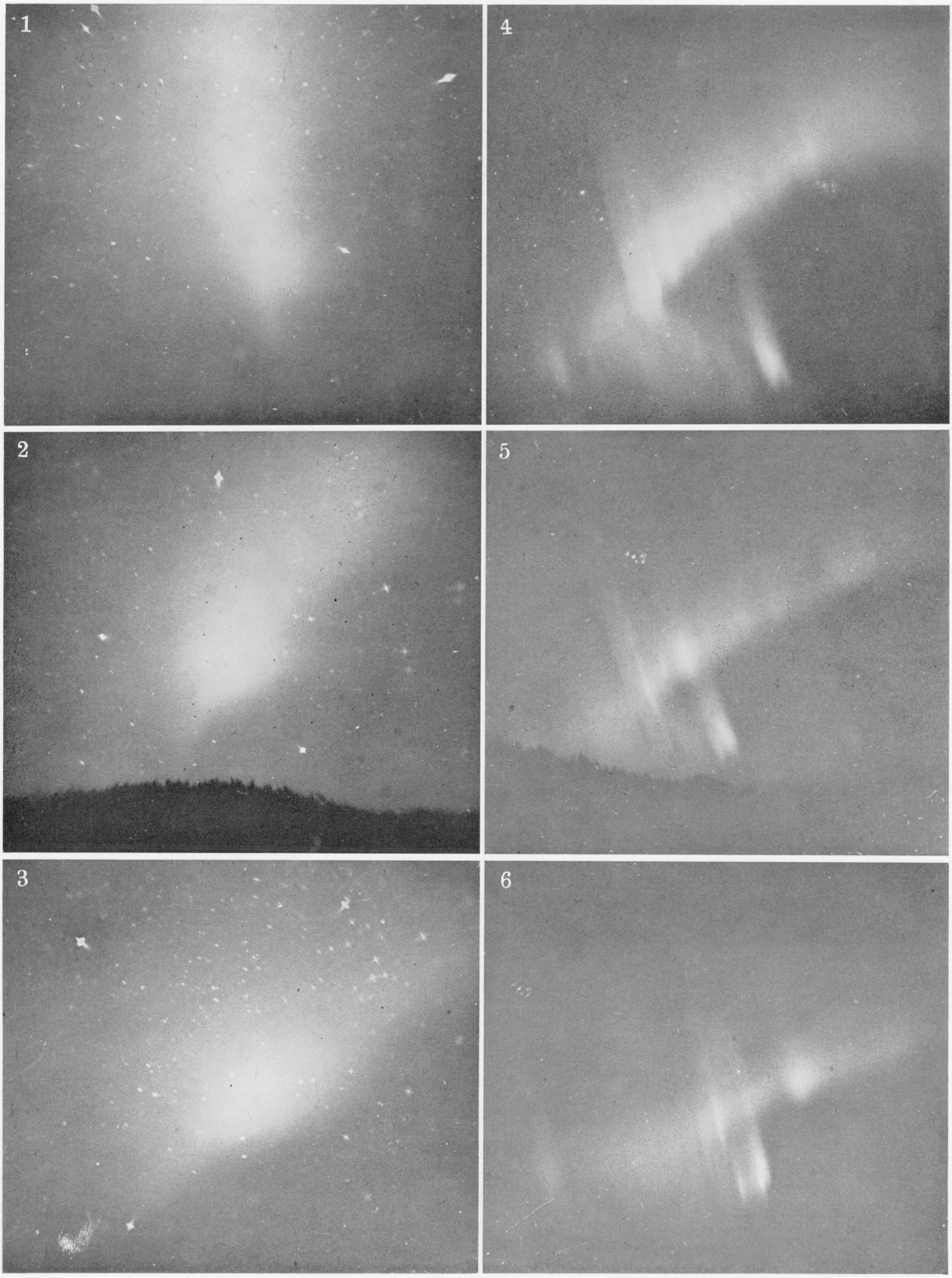
1. Auroral arc, photographed from Kongsberg August 27th, 1934 at $23^h\ 29^m\ 17^s$ MET.
2. The same arc photographed simultaneously from Løkken Verk.
3. Diffuse, pulsating arc, photographed from Lillehammer, January 27th, 1935, at $20^h\ 59^m\ 48^s$ MET.
4. The same arc photographed simultaneously from Tømte.
5. The same arc photographed simultaneously from Oslo.
6. The same arc photographed simultaneously from Kongsberg.

Plate II:

1. The same diffuse, pulsating arc photographed from Lillehammer at $21^h\ 11^m\ 25^s$ MET.
2. The same arc photographed simultaneously from Tømte.
3. The same arc photographed simultaneously from Kongsberg.
4. Auroral curtain photographed the same night from Lillehammer at $1^h\ 51^m\ 28^s$ MET.
5. The same, photographed simultaneously from Tømte.
6. The same, photographed simultaneously from Kongsberg.



C. Størmer.



C. Størmer.