

REMARKABLE AURORA-FORMS FROM SOUTHERN NORWAY

I. FEEBLE HOMOGENEOUS ARCS OF GREAT ALTITUDE

BY CARL STØRMER

(Institute of Theoretical Astrophysics, Blindern)

1. Introduction.

During the period of about 25 years since my first photographic aurora stations in southern Norway began their work, several thousand photographs of aurorae have been taken either as single pictures or as sets of pictures from 2, 3 or 4 stations simultaneously, for measuring the height and situation of the aurorae.

Among the aurora-forms observed, there is a certain number of very strange and infrequent forms some of which, as far as I know, not even observed near the zone of maximum frequency of aurora.¹

It would seem, therefore, that a monograph on these remarkable forms might be desirable and among those to be studied are:

1. Feeble homogeneous arcs at great altitude.
2. Pulsating arcs.
3. Red arcs.
4. Red patches.
5. Pulsating patches.
6. Cloud-like aurorae.
7. Sunlit auroral rays.

2. Height of feeble homogeneous arcs compared with the common kinds.

From the many hundred sets of aurora-photographs taken from Oslo and connected stations in the years 1911—1922, statistics were made of the height of the different forms.

In particular, the height of the aurora arcs near zenith in Oslo have a maximum of frequency between 100 and 110 km, as the following extract shows:²

¹ Carl Størmer: Über die Probleme des Polarlichtes, § 7. Ergebnisse der kosmischen Physik, I Band, Akademische Verlagsgesellschaft, Leipzig 1931.

² Carl Størmer: Resultats des mesures photogrammetriques des aurores boréales observées dans la Norvège méridionale

Frequency of measured aurora points
of homogeneous arcs near zenith in
Oslo 1911—1922.

Interval, limits included	Frequency
80—90 km	1
90—95 »	4
95—100 »	13
100—105 »	19
105—110 »	16
110—115 »	4
115—120 »	1

These arcs formed the southern boundary of the aurora occurring at the same time.

But besides this type of aurora arc, there occurs in Oslo on rare occasions another type, which consists of a thin sharply limited homogeneous arc, some degrees wide and with very feeble luminosity. This arc is, in general, situated near zenith, lasts from half to about one hour, and during its appearance is far from other aurorae, which, if any, occur only near the northern horizon.

The height of these remarkable arcs is about twice that of the height of the common arcs mentioned above.

I saw such an arc for the first time the 22 February 1911 and on that occasion obtained some measurements of it.¹ The next time I succeeded in obtaining

de 1911 à 1922. Geofysiske Publikasjoner Vol. IV, No. 7. Fig. 18, curve II.

¹ Carl Størmer: Sur les trajectoires des corpuscules électriques etc. § 26 and 27, Sec. memoire, Archives des sciences physiques et naturelles, Genève 1912, and Het Pollicht van 22 Februari 1911, Hemel and Dampkring 1911.

simultaneous photographs of such an arc was on 29 September 1930. New measurements were obtained on 10 March 1932 and on 9 December 1933.

3. The Arc of 29 September 1930.

After sunset that day I discovered the aurora as long thin rays in the north. I immediately telephoned to my aurora stations, Oslo Observatory, Oscarsborg, Kongsberg and Tømte, and hurried to the observatory to get everything in order. But my assistant Tveter was not at home and I was obliged to do everything myself. For this reason I had not time to watch the development of the aurora so closely. I only remember that the rays in the north were very long and thin, reaching almost from the horizon to zenith; they were probably lying in the sunlit atmosphere.

After a while, the rays disappeared and gave place to a most remarkable arc near zenith from E to W just of the same type as the arc observed on 22 February 1911. The arc remained across the heaven for about half an hour without sensible change. It was feebly luminous and without rays. Looking at it through a pocket-spectroscope of Lord Rayleigh's construction (at 20^h 12^m) I could not discover any lines; even the green aurora line was not visible.

At 20^h MET I obtained telephonic connection with Oscarsborg, where my excellent assistant Harry

Larsen was doing the photographic work. We immediately began to take simultaneous photographs and 22 sets were taken before the arc disappeared. At 20^h 19^m my assistant Carsten Borchgrevink at the station Tømte was ready for work and took the last 7 sets simultaneously with us. I did not succeed in getting connection with my station Kongsberg.

The situations of the stations Oslo (*C*), Oscarsborg (*O*), and Tømte (*T*) are seen on Plate XIV. The length of the base lines were:

$$C-O=27.36 \text{ km}$$

$$C-T=46.68 \text{ »}$$

$$O-T=73.73 \text{ »}$$

The following sets were usable (see Table I).

The subsequent pictures with one and two minutes exposure, gave no trace on the plates; the arc was in fact now very feeble and disappeared at 20^h 30^m.

In the north there remained a feeble glow near the horizon; some feeble rays were photographed at 23^h 30^m, but the pictures were too faint for use.

The same situation remained unchanged til 3^h; only a feeble glow near the northern horizon; in the pocket-spectroscope directed towards this glow, the aurora line was visible till about 2^h 30^m.

From a series of observers I got visual observations of the arc; these will be mentioned later.

Table I.

Picture No.	Time MET (Mid. exposure)	Exposure	Stations	Reference stars
1	20 ^h 0 ^m 6 ^s		<i>C—O</i>	β, δ Herculis, α Ophiuci
2	» 1 24		<i>C—O</i>	β, δ » α »
3	» 2 6		<i>C—O</i>	α, γ Lyrae, 0 Herculis
4	» 2 53	15 ^s	<i>C—O</i>	α, γ » 0 »
5	» 3 44	32	<i>C—O</i>	$\beta, \delta, \varepsilon$ Herculis
6	- 4 25	30	<i>C—O</i>	γ , Herculis, α, β, γ Serpentis
7	» 5 47	25	<i>C</i>	$\beta, \delta, \varepsilon$ Herculis
8	» 6 52	25	<i>C</i>	$\beta, \delta, \varepsilon$ »
9	» 8 13	55	<i>C</i>	α, γ Lyrae, 0 Herculis
10	» 9 18	45	<i>C</i>	$\alpha, \gamma, \varepsilon$ Cygni
11	- 10 15	37	<i>C</i>	$\alpha, \gamma, \varepsilon$ »
13	» 14 9	73	<i>C—O</i>	α, γ Lyrae, 0 Herculis
14	» 15 50	69	<i>C—O</i>	$\delta, \varepsilon, 95$ Herculis, α Ophiuci
15	» 17 41	66	<i>C—O</i>	$\gamma, \varepsilon, \zeta$ Cygni
16	» 19 37	55	<i>C—O</i>	α, γ Lyrae, 0 Herculis, β Cygni
-	-	-	<i>C—T</i>	α, γ » 0 » β »
-	-	-	<i>O—T</i>	α, γ » 0 » β »
17	» 21 25	50	<i>C—O</i>	$\beta, \delta, \varepsilon, 0$ Herculis
-	-	-	<i>C—T</i>	$\beta, \delta, 0, \gamma$ » $\beta, 41$ Cygni
-	-	-	<i>O—T</i>	γ Lyrae, $\beta, \delta, \varepsilon, 0$ Herculis, $\beta, 41$ Cygni
18	» 23 25	60	<i>C—O</i>	γ, β, δ Pegasi, 10 Lacertae, α, β, δ Andromeda, 1 Vulpeculae
-	-	-	<i>T</i>	95 Herculis, 72, α Ophiuci

**4. The Height-Measurements of the Arc
29 September 1930.**

The first pictures Nos. 1 to 6 were highly under-exposed; it was necessary to take diapositives and new reinforced negatives of the plates and this reinforcement made it possible to get usable results; for assistance during this difficult work I am indebted to Mr. Worm Petersen and Miss Monsen.

The plates have been measured up to 5 times with essentially the same results. Here are given the last measurements made by my assistant, Mr. Anda, and myself in the spring of 1935.

On Plates I—V are seen the sketches made from the negatives direct by the projection method and in Table IV are given the result of the measurements. The meaning of the letters are as follows:¹

- u_1 and u_2 are the values of the base distance u of the aurora point as seen from the main and from the secondary station.
- p is the parallax,
- h is the height,
- a is the azimuth, reckoned from south westwards,
- H is the height above the earth's surface,
- D is the distance from the main station to the projection of the aurora point on the earth's surface,
- H_1 is the height of the earth's shadow over the projection of the aurora point and
- T is the distance from the projection of that point along the earth's surface to the point where the sun ray touches the earth (no account is taken of refraction).

The angles u_1 , u_2 , p , h and a are reckoned in degrees and tenths of degrees, the heights H and H_1 and the distances D and T in kilometers.

On the sketches the reference stars are provided with small segments in the direction of the vertical, and, in the direction of the displacement, with values of the angles h and u marked. On the end of the vertical segment, the value of the azimuth reckoned from south towards west is given, if the sketch belongs to the main station. The double circle gives the optical centre of the picture. The geographical situation is given on Plate XIV.

Reproductions of three of the best sets of pictures are seen on Plate XVI.

It is interesting to take the means of the measurements of each picture, for the lower and upper border of the arc. On all pictures, except Nos. 5 and 6, the left border is the lowest one:

Lower border:

No.	1	2	3	4	5	6	13	14	15	16	16*	17	17*	Mean
H	217	205	170	227	203	199	180	180	187	181	194	196	194	195

Upper border:

No.	1	2	3	4	5	6	13	14	15	16	16*	17	17*	Mean
H	256	240	272	227	223	227	214	226	221	225	228	231	225	232

Here 16 and 17 mean the pictures with base-lines $O—C$, 16* and 17* those with base-line $O—T$.

The best of the earlier measurements gave as mean for the two borders 193 and 234 km, very near these values.

5. Some Measurements from Single Pictures.

If we take the mean height 194 km as height of the lower border of the arc, some of the single pictures can be used to find the geographical situation of the arc.

This has been done on picture O 18 along the eastern part (see Plate XIV). From this it is seen that the arc stretched from Stockholm towards the north of Scotland.

From one of the visual observations which will be mentioned in the next section, the arc was seen down to about 5° over the horizon on both sides. This corresponds to a length of about 2000 km.

6. Some visual Observations of the Same Arc.

In newspapers and by radio I suggested that observers should send me visual observations of the arc and I received a series of more or less complete reports, the best being from Mr. Olaf Hassel at Darbu (latitude 59° 39', longitude 0° 57' 15.2" E of Oslo Observatory). His observations of the successive situations of the arc are very good, and, combined with my photographs, they might be used for reliable height measurements. In fact several of his drawings are almost simultaneous with the photographs.

His sketches are reproduced on Plate XIII. He says that "the arc disappeared at 20^h 30^m 0^s MET, and the last trace of the arc was seen in Serpens in W." At 20^h 39^m he observed on the northern sky faint diffuse and broad bundles of rays.

¹ Carl Størmer: Measurements of aurorae with very long base-lines, § 3, Geofys. Publ. Vol. IX, No. 3.

From Mr. Thor Haug, Farsund (Lat. $58^{\circ}.1$, Long. $6^{\circ}.8$ E Gr.) came the following report:

"A friend and I saw the aurora at $20^{\text{h}} 10^{\text{m}}$ and observed it for ten minutes. It had the form of a long continuous stripe very nearly parallel to the Milky Way on the same side as the polar star. The distance from the Milky Way was half the distance from the pole star to the Milky Way. We also saw some flickering near Ursa minor, but these flickerings were well separated from the aurora arc."

Mr. v. Ditten, Skravestadverket near Sandefjord (Lat. $59^{\circ}.2$, Long. $10^{\circ}.3$ E Gr.) says:

"The situation of the arc was as follows: It began in W a little south of the place of sunset, continued upwards as a straight line, made a great turn towards south and continued straight over the Crown (Corona borealis) which was entirely in it, and passed through zenith, through Andromeda and the A. Nebula until somewhat further towards E. Twenty minutes after the first observation it had moved so far southwards in W and northwards in E that the above-mentioned stars were out of it, probably on account of the daily motion of the stars."

This observation is of interest in so far as it gives an idea of the form of the arc near the western horizon. The turn towards south is also seen on sketch O 6.

Mr. Gulbrandsen sent the following report from Lampeland (Lat. $59^{\circ}.8$, Long. $9^{\circ}.6$ E Gr.):

"In response to your broadcast request yesterday evening (29 September) I give the following observations:

The aurora had the form of a strong arc with a breadth like that of a great rainbow, but as a much larger circle. The luminosity was like a strong search-light. Towards west the circle-formed arc had an elbow a little to the right of the intersection with the Milky Way."

Mr. L. Buchholz, Horten (Lat. $59^{\circ}.4$, Long. $10^{\circ}.5$ E Gr.) sent the following observations:

"When I first saw it, it had the form of a homogeneous arc with a light stronger than common aurorae here. It had the form of a small circle. Its length was from about 5° over the Eastern, to about 5° over the Western, horizon. No part of the arc was to the north of zenith and its highest point was in a direction SSW and about 5° to 10° south of zenith. The breadth of the arc was approximately equal to the distance between δ and ζ Orionis. About 30° over the western horizon the arc had a feeble

elbow where it changed its direction towards north and grew smaller towards the horizon. I first thought it was a search-light. The arc was seen about half an hour and disappeared from the west during the last 10 minutes. It was as if somebody made a stroke over a white streak with a dark painting brush. The light was the whole time white, there being no trace of other colours. I am sorry that I did not observe the time closely. The other observations, however, are rather good because I was discussing these with another observer."

The high rays preceding the aurora arc were observed in Holmestrand (Lat. $59^{\circ}.5$, Long. $10^{\circ}.3$ E Gr.) by two ladies, Dorothea Bonnevie and Margit Støren, who sent me the following description:

"Yesterday about half past seven p. m. (MET) we observed some very fine rays from NE to NW. We saw first a single aurora ray which varied in luminosity. Then there came more and more rays, which flickered and succeeded each other. They formed a broad girdle and resembled search-lights. To the west of the broad girdle we saw single, equally broad, rays which suddenly increased very much in luminosity, then faded and disappeared. It seemed as if the longest one moved westwards."

7. The Arc of 10 March 1932.

A similar high isolated arc was observed and photographed from 3 of my stations in the evening of 10 March 1932. I did not see the beginning of the aurora that evening, but I received from Olaf Hassel in Darbu the following observations¹:

". . . Some minutes past 20^{h} MET I happened to see some aurora rays in the north, near the horizon.

$20^{\text{h}} 29^{\text{m}}$. The lower arc showed great intensity in different parts. The situation is marked on the accompanying star map (not reproduced here).

20.36. The upper arc ascending.

20.37. The two arcs fainter.

20.38. The lower arc has tendency to dissolve in rays.

20.39¹/₄. The first long rays appear in the western part of the upper arc.

20.40. Upper arc dissolves in a series of rays.

20.45. The rays are fading away.

20.46. No more aurora.

20.50/51. Very feeble glow from a cloud-like aurora in N—NNE and very faint diffuse rays in NW.

¹ The first part of these observations, concerning the two auroral arcs in the north, is not given here.

20.55. A long very faint and diffuse ray over δ Cygni. Disappears at once.

20.57. Other short-lived diffuse rays in Cygnus along the horizon.

21.3. Broad diffuse rays in the western part of Cygnus.

21.5. The rays in Cygnus are moving west towards Andromeda.

21.7. Everything disappeared.

After a period with no aurora a southern arc began to appear¹ at 21.50.30 as a small stripe in the west between Aldebaran and the Pleiades up to Auriga.

22.15. The southern arc up to zenith. A new arc in the north.

22.25. The southern arc stretches between τ , κ and ϑ Ursae majoris and further between λ and ψ of the same constellation.

22.29. The southern arc disappeared, and simultaneously the arc in the north dissolved in rays."

We shall come back to the rest of Hassel's observations later.

As soon as I saw the aurora I warned my aurora stations Tømte, Oscarsborg and Kongsberg and at 21^h 24^m the photographic work could begin at my stations Oslo Observatory and Kongsberg and at 22.20 Oscarsborg joined in. The stations Oslo (C), Oscarsborg (O) and Kongsberg (K) are seen on Plate XIV. The lengths of the base-lines C—O and C—K are:

$$\begin{aligned} C-O &= 27.36 \text{ km} \\ C-K &= 65.16 \text{ »} \end{aligned}$$

The following successful sets of pictures were taken (Table II).

As the arc was very faint, long exposures were chosen and as it did not move at all, almost every picture succeeded. The pictures 18 to 22, however, were taken from Oslo alone, the Oscarsborg plate being spoiled. These pictures have not been used.

At the same moment as the arc disappeared the low arc in the north dissolved in rays and draperies, which were followed by pulsating surfaces and coruscations. Of this development were taken pictures Nos. 25 to 46, among which 3 sets from two stations, 10 sets from 3 stations, and 15 single pictures were successful. Simultaneously with this work, Mr. Hassel made the following observations:

¹ I had already seen this arc and had taken 11 sets of pictures of it when Hassel saw it.

Table II.

Picture No.	Time MET Mid. exp.	Exp.	Stations	Reference stars
2	21 ^h 26 ^m 15 ^s	82 ^s	C—K	ε Arietis, λ , μ Ceti
3	" 28 9	84	C—K	η , f Tauri, ζ Arietis
4	" 29 47	62	C—K	" λ " " "
5	" 31 45	122	C—K	" " " " " "
6	" 34 4	121	C—K	" " " " " "
7	" 37 43	120	C—K	λ , ξ " , α Ceti
8	" 40 15	121	C—K	" " " " " "
9	" 44 11	205	C—K	" " " " " "
10	" 48 00	193	C—K	" " " " " "
11	" 51 21	181	C—K	λ , ε , η , τ Tauri
13	" 58 53	180	C—K	λ , ξ , ν "
14	22 1 33	93	C—K	λ , ξ , τ "
15	" 3 46	122	C—K	β Tauri, α , β Aurigae
16	" 6 23	121	C—K	α , β , δ Ursae majoris
17	" 9 4	120	C—K	λ , ξ , α Tauri
23	" 21 44	122	C—O	β , ζ , ι "
24	" 25 16	120	C—O	κ , ϑ , 10 Ursae majoris (The arc disappeared)

22^h 35^m. The rays have faded away and a broad arc in the north has taken their place.

22.37.30. The new arc dissolved in rays.

22.40. Pulsating aurora.

22.45. Pulsations and simultaneously diffuse rays.

For 5^m were seen many long rays some of which were faint.

22.50. No more rays. Feebly pulsating aurora in Cygnus and Lyrae.

22.53. Again flaming aurorae, but only for a little while. Then nothing.

23.9 and 23.19. Some feeble rays.

23.11 to 23.12. Everything disappeared.

The observations ended at 0^h 30^m. No aurora since 23.12.

8. The Height-Measurements of the Arc 10 March 1932.

The sketches from the negatives were first made by myself and then measured and calculated by my assistant Falch in the year 1932. A new independent drawing and measurement was made in May 1935 by Mr. Anda, the results being given in Table IV. The sketches made from the negatives are seen on Plates V—X and some of the photographs on Plates XVII and XVIII.

On this occasion the exposures were chosen much longer than before and this secured better pictures. Some of them, however, were very difficult to measure because the arc itself was so faint that it was difficult to photograph it even with an exposure of some minutes.

I am sorry that no pictures were obtained from the station Tømte. In fact, the arc had a rather unfavourable situation for the base-line $C-K$ which gave small parallaxes. On the other hand, the pictures were very good near the distant part of the arc and showed many stars, which gave reliable measurements in spite of the parallaxes so small as one to two degrees.

The mean height of the lower and upper borders were:

Lower border:

No.	2	3	4	5	6	7	8	9	10
H.	163	187	191	190	189	191	194	184	210
	11	13	14	15	16	17	23	24	Mean
	187	174	191	208	230	175	188	212	192

Upper border:

No.	2	3	4	5	6	7	8	9	10
H.	215	225	221	229	220	227	247	227	220
	11	13	14	15	16	17	23	24	Mean
	217	210	231	217	259	221	242	230	227

This is very near the results we found for the arc of 29 September 1930, where the mean heights of lower and upper borders were 195 and 232 km.

The first measurements of this arc by Mr. Falch and myself gave for lower and upper border the mean heights of 203 and 251 km respectively, but on closer inspection I became convinced that these old measurements were not so reliable as the new ones here given.

On the pictures of the lowest and most distant part of the arc, its peculiar form is understood if one remembers that the arc has the form of a transparent thin and long surface described by lines of magnetic force and situated almost along a circle of latitude. As this surface is seen in the direction of its extent E—W, its curvature makes us regard it tagentially along the most distant parts. See, for instance, pictures Nos. 7, 8, 9, 10, 13 and 17.

On Plate XIV is marked the geographical situation of the arc, found from all the measured points. During the first period of its appearance the arc did not continue eastward (see, f. inst., the visual observations from Mr. Eriksen, mentioned in the next section). Later, it was seen but very faint past zenith.

If we compare the situations of this arc and the arc from 29 September 1930, this arc did not go so far east and was situated more northerly than the other.

9. Some Visual Observations of the Arc of 10 March.

A series of reports also arrived this time, but most of them were of minor interest. Some from northern parts of Scandinavia described other arcs seen towards the northern horizon in Oslo, and many had no definite time observations, which made them illusory.

We have already mentioned the excellent observations from Hassel at Darbu. He also sent a series of sketches on star maps, but as these do not give more details than those already found on the photographs from Oslo and Kongsberg, they are not reproduced here.

From Hans A. Eriksen, Åsa, Steinsfjorden (Lat. $60^{\circ}.1$, Long. $10^{\circ}.4$ E Gr.) I received the following report:

"I observed from Åsa electrical power station at the head of Steinsfjord. The view towards west is free, but towards east it is hindered by the wood Krokskogen. I am interested in astronomy and I like to look at the sky every night it is clear. On Tuesday 10 March I went out about $21^{1/2}$ to see if anything of interest was to be seen in the sky. No clouds were visible, but in NW an aurora belt without rays was seen. As I looked westwards, I saw something which looked like a comet's tail rising up from the horizon with decreasing intensity till it disappeared between Aldebaran and the Pleiades. On Fig. 1 is seen the phenomenon at $21^h 38^m$. As aurora generally do not look like this I wondered if it was the zodiacal light. But it now changed into a luminous ray which increased in intensity and developed higher and higher upwards. About 22^h it had the appearance of a rainbow over the entire sky from west to east almost through zenith. Like this the arc remained quite without motion for several minutes and I wished I had a camera to photograph it. About $22^h 15^m$ the arc bent like a snake at the western horizon. It then disappeared near zenith and then successively towards the eastern and western horizon, but soon afterwards it developed upwards again to an entire arc, thereafter remaining steady. At $22^h 15^m$ the arc was as far to the west of Aldebaran as it is to the east on the sketch 21.38.

As it was 20° below zero Celcius, I went indoors at $22^h 30^m$ to get warm. When I went out again some time later the arc had disappeared, but in the north the aurora had developed with bright rays."

From Karl Westman in Råda, Sweden (Lat. $60^{\circ}.0$, Long. $13^{\circ}.6$ E Gr.) I was sent the following description:

"... It was lying like a narrow and completely steady stripe, between $21^h 30^m$ till $22^h 30^m$, from the

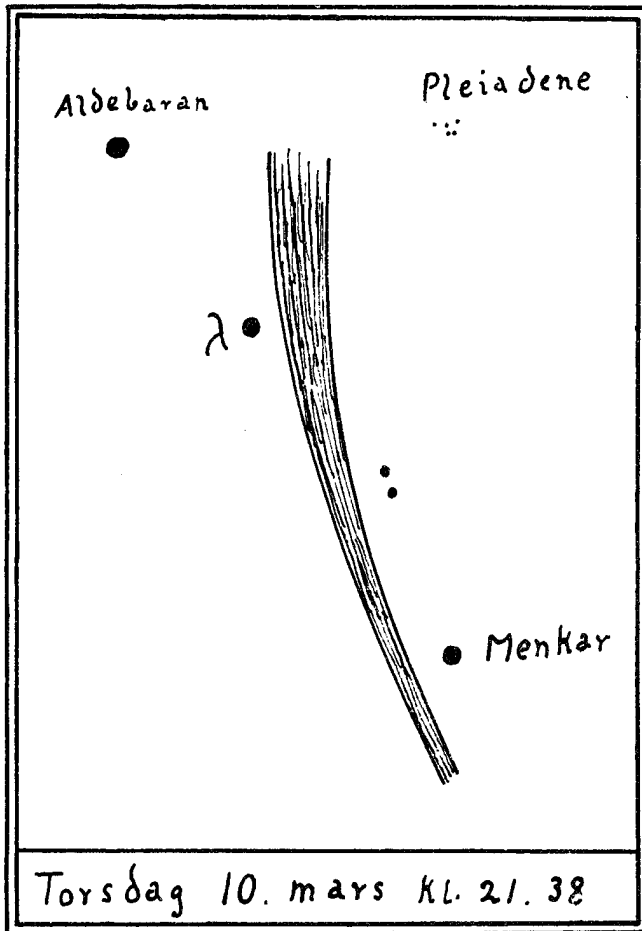


Fig. 1.

western horizon up through zenith, covering the environs of the Pleiades like a diffuse shine and continued with less intensity towards east . . .”

The arc was also seen by two observers near Bergen (see Plate XIV) where it had a comet-like appearance and a position corresponding to the calculated situation over the North Sea.

10. The Arc of 9 December 1933.

A most remarkable similar arc was photographed in the late evening of 9 December 1933, and in contrast to the two preceding cases of 29 September 1930 and 10 March 1932, this arc appeared at the end of a long and fine auroral display.

At 17^h 55^m MET I received a telephone call from my assistant Busengdal at Kongsberg. He said that he saw a double arc in the north. At the same time, my assistants Albert Tømte at the station Tømte, and Høstmælingen at the station Lillehammer, telephoned that an aurora was visible.

At Oslo, however, it was completely overcast and there was nothing to see, but I decided, nevertheless, to try the following experiment:

I got into telephonic connection from Oslo with the three stations, Kongsberg, Tømte and Lillehammer, and from a simultaneous conversation with all three, the work was throughout directed from Oslo. The stations informed Oslo about the form and situation of the aurora among the stars, and, *without seeing the aurora*, the photographic exposures were conducted and registered from Oslo and with entire success.

Among the 73 simultaneous exposures from 3 stations the following were usable for height measurements:

39	simultaneously	from	2	stations
13	—»—	3	»	

and, moreover, 12 pictures from one station could be used for determination of situation if we suppose for the height a reasonable value.

At Oslo, the time was observed and the notes were written by Sandøy and Anda, and the photographic work conducted on the telephone by Tveter and myself. At the stations Kongsberg, Tømte and Lillehammer, the photographs were taken by orders from Oslo, by Busengdal, Albert Tømte and Høstmælingen.

As to the general development of the aurora, the following may be of interest:

From 18^h 25^m until 18^h 52^m, 15 sets were taken of an arc in the north, with some rays nearer down to the northern horizon.

A new arc now began to develop under the first. The upper moving upwards, the second disappearing again.

At 19^h 27^m fine rays and curtains developed at the lower border of the arc. This development lasted until about 19^h 40^m.

At 20^h the arc was again fine, but disappeared half an hour later.

At 21^h 15^m the arc had reappeared and was double and very splendid for an hour. Then at 22^h 27^m fine rays and curtains began to develop under the arc and this development which represented the maximum of brilliancy of the aurora that evening, lasted to about 22^h 55^m.

At that time a new arc suddenly began to develop in the south-eastern sky; it looked like a ray or a comet's tail and stood quite isolated and far more south than the aurora seen earlier; of this, only rather

faint pulsating patches near the northern horizon remained.

The assistants thought that this arc was an auroral ray and unfortunately we did not choose the exposure time as long as desirable, in particular, the pictures at Tømte and Lillehammer being highly under-exposed. By taking diapositives and from these new negatives, the plates could nevertheless be measured with good precision, thanks to the large parallax. The arc disappeared at about 23^h 15^m.

Some rays in the north were photographed from the 3 stations at 23^h 35^m, but the aurora then faded away very rapidly. At midnight no trace of aurora was seen and as this state remained for more than an hour, at 1^h 15^m MET I gave the signal to cease work.

Of the high arc the following pictures were taken (Table III).

Table III.

Picture No.	Time MET Mid. exp.	Exp.	Stations	Reference stars
66	22 ^h 59 ^m 53 ^s	112 ^s	K—T—Li	ζ Pegasi, ω, ϑ Piscum
67	23 2 4	111	K—T—Li	" " " " "
68	" 4 13	101	K—T	α " " " "
69	" 6 25	77	K—T—Li	75 " ω, λ, ϑ "
70	" 8 10	51	K—T—Li	ζ Pegasi, ϑ, λ Piscum
71	" 11 22	68	K	75 " ω "
72	" 14 14	77	K	ζ Andromedæ α, ζ Pegasi, ϑ Piscum

Among these, K—T 66, K—T 67, K—T 68, K—Li 69 and K—Li 70, could be used for height measurements, K 71 and K 72 for geographical situation.

11. The Height Measurements of the Arc 9 December 1933.

The negatives were drawn and measured by Anda and myself first in December 1933, and then more carefully by Anda in May 1935. The sketches of the negatives are seen on Plates XI and XII and photographs of the arc on Plate XVIII.

The situations of the stations Kongsberg (K), Tømte (T) and Lillehammer (Li) are seen on Plate XV. The lengths of the base-lines K—T and K—Li were

$$K—T = 104.94 \text{ km}$$

$$K—Li = 165.35 \text{ "}$$

In the table IV at the end of this paper the results of the measurement are given. It was very difficult to fix the borders of the arc on the Lillehammer

picture because it was so under-exposed and therefore the heights with the base K—Li are a little uncertain in spite of the great parallax.

For the borders we found the following mean heights in km:

Lower border:

No.	66	67	68	69	70	Mean
H	196	199	196	194	199	197

Upper border;

No.	66	67	68	69	70	Mean
H	210	218	216	210.5	226.5	216

From this it is evident that the arc was of the same kind as the arcs of 29 September 1930 and of 10 March 1932.

12. Visual Observations of the Same Arc.

From my indefatigable observer Mr. Olaf Hassel, Darbu, I received 83 star maps with sketches and a series of observations of the aurora of the 9 December, made from 18^h 23^m until 1^h next morning. Among these the following relate to the high arc: See Figs. 2, 3 and 4.

22^h 48^m MET the rays faded away and simultaneously flaming aurora began, which again stopped at 21^h 57^m.

22^h 55^m or, perhaps a little before, a portion of an isolated arc appeared in W.

23^h 15^m the arc in the west was fading away and simultaneously an arc with rays appeared close to the northern horizon. Some minutes later they disappeared.

23^h 25^m. Several small luminous patches in a feeble glow in the north. Later the aurora grew fainter and fainter and disappeared. At 1^h in the morning observations ceased.

It is remarkable that at the same moment as the high arc disappeared, aurora with rays appeared near the northern horizon. The same phenomenon was observed with the arc of 10 March 1932.

As the arc was going down through the western horizon, I was very interested to know its further extension westwards. I was therefore very happy to receive a letter from Professor Evershed, Ewhurst, England, dated 20 January 1934, in which he says:

"I have now got reports of the aurora of Dec. 9. It was observed by Mr. Housman at the Seaton Observatory, Workington (lat. 54° 40', long. 3° 30' W) 19^h to 22^h GMT. At 21^h 10^m to 21^h 30^m there was

a great outburst of bright golden streamers 70° extent, 345° centre. As this faded a faint portion of an arc appeared from the horizon below ϵ Pegasi passing between ς and η Draconis through δ and ϵ Ursae Majoris, vanishing towards the east. Luminosity about one half galaxy which it crossed in NW sky. About 6° wide.

I estimate from this, that the highest part of the band was about 29° in altitude and the height above the ground in latitude 58° would be 220 km in agreement with your measures. As seen from Workington it extended from the western horizon, but vanished before reaching the east horizon. This aurora appears to have been extensively observed in Scotland and I enclose a letter received from the Meteorological Office at Edinburgh. You will no doubt receive full details from Dr. Mitchell."

There is no doubt that the arc seen from Workington is the same as that measured from our stations in Norway, the time, after $21^h 30^m$ GMT, that is after $22^h 30^m$ MET, corresponding to the interval $22^h 55^m$ to $23^h 15^m$ where the arc was observed and photographed from southern Norway. As the arc as seen from Workington extended to the western horizon it must have continued far more to the west than seen on the map, Plate XV.

In the observations which I received from the Meteorological Office at Edinburgh and from Dr. Chrichton Mitchell, no special mention was made about this arc, only about the preceding aurora.

13. Earlier Visual Observations of Similar Arcs.

In order to find if similar arcs may have been observed in Oslo earlier than in 1911, I have consulted the detailed report on aurorae in Norway from the earliest observations up to those of 1878, collected by the excellent observer Sophus Tromholt¹. The following observations, which I give in extenso, probably refer to such arcs:

1847. October 6. Christiania.

12^h eigentümliches Nordlicht in WSW. Es hatte die Gestalt einer ruhigen Kerzenflamme und Ähnlichkeit mit einem geraden Kometenschweif, war gegen den Horizont um 45° nach S geneigt, 15° lang, 3° breit. Nach $1/2$ Stunde waren Form und Lage dieselben, nur hatte die Erscheinung sich um so viel gehoben, daß

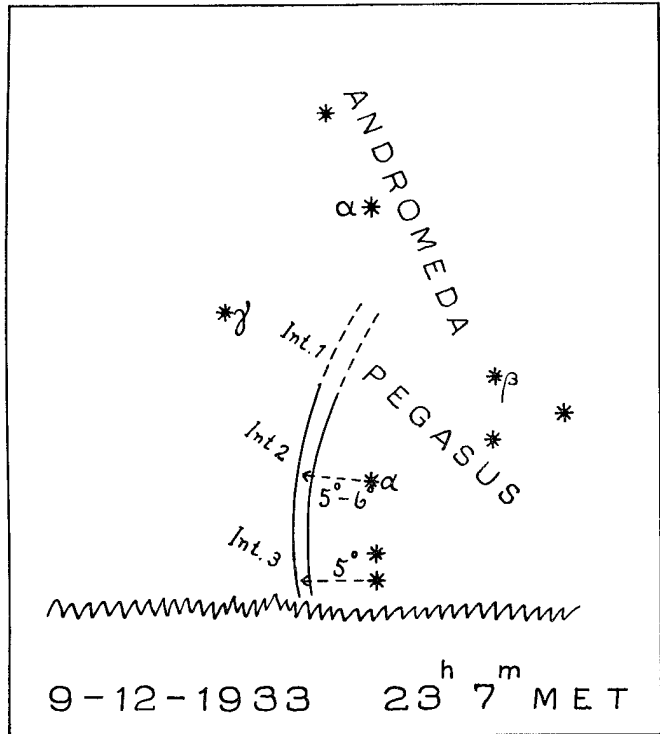


Fig. 2.

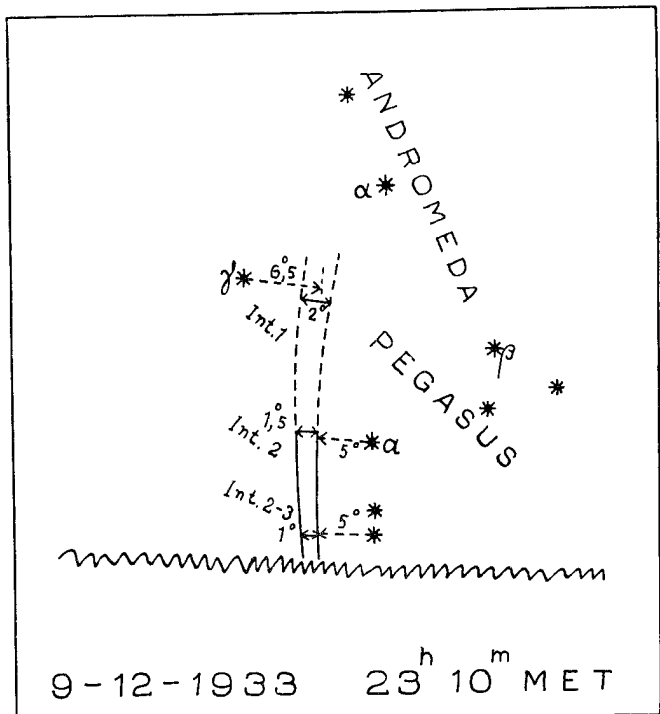


Fig. 3.

¹ Catalog der in Norwegen bis Juni 1878 beobachteten Nordlichter zusammengestellt von Sophus Tromholt, herausgegeben von J. Fr. Schroeter, Christiania 1902.

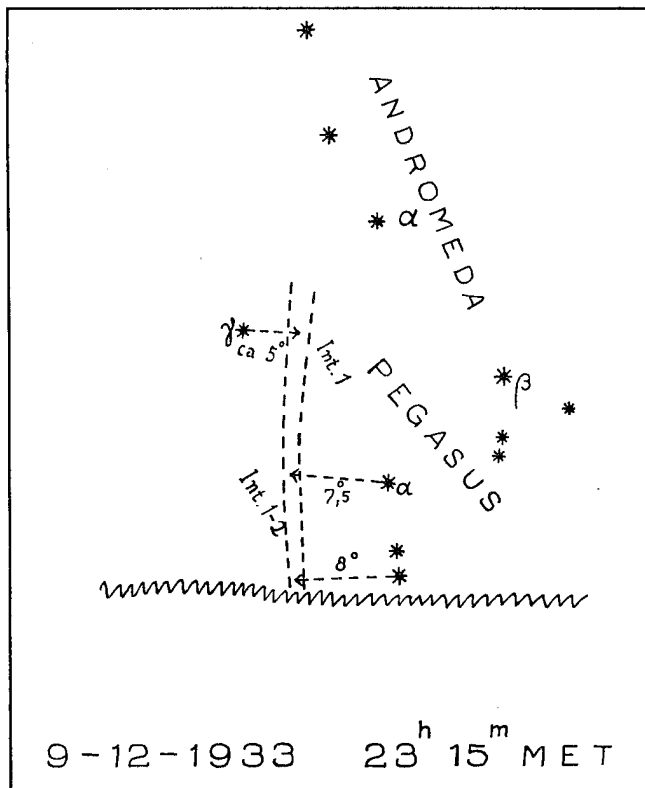


Fig. 4.

die Wurzel einige Grade über dem Horizont stand; Glanz und Länge hatten zugenommen. Saturn, anfangs an südlicher Grenze, war jetzt von dem Lichte eingehüllt.

1858. Februar 15. Christiania (3 reports.)

1. Prachtvolles, strahlendes Nordlicht von 7^h an. Ein ruhiger Bogen beinahe durch das magnetische Z blieb fast eine Stunde (8^h—9^h) lang stehen ohne merkbare Veränderung der Gestalt oder Lage. Breite kaum 3°. Kleinste Zenithdistanz (d. h. im magnetischen Meridian) 8^{1/2}^h: 15°. 8^h 25^m endete der Bogen bei ϵ Virginis; er ging durch β Aurigae und zwischen η und ζ Aurigae auf der einen, ϵ Aurigae auf der anderen Seite.

2. 7^h helles Segment. 8^h Bogen E 10°, N—W 30° S durch Z.

3. Merkwürdiger Bogen vor kaum 2° Breite und ungefähr 23° südlicher Zenithdistanz, sehr regelmäßig mit Ausnahme des westlichen Endes, welche den Horizont nicht erreichte.

1865. Februar 15. Christiania.

Schönes Nordlicht in der Gestalt eines sehr langen und zum Teil stark leuchtenden Bogens, der 10^h sich von Arcturus in E über den Löwen, Castor und

Hyaden hin bis W erstreckte, wo er von einer dunklen Wolkenbank verdeckt wurde. Er veränderte langsam seine Lage im Verhältnis zu den Sternen so daß er 10^{1/4}^h ein wenig rechts von η Bootis, dicht südlich vorbei Pollux ging und λ Orionis berührte. Die Länge des Bogens betrug wahrscheinlich ca. 40°, er war überall beinahe von gleicher Breite und zwar sehr schmal, besonders anfangs (kurz vor 10^h) als er nur ein Paar Grade breit war, zu der Zeit wo er verschwand oder sich teilweise in schwachleutende, nebelartige Partien auflöste, breitete er sich mehr aus und war da bis 4° breit. Die westliche Hälfte des Bogens zeigte das stärkste Licht. Mehrmals erlitt die Lichtstärke bedeutende Veränderungen. Auch gegen N am Horizonte zeigte sich Nordlicht, jedoch nur als eine unförmliche Masse ohne Strahlenspiel.

1867. Februar 12. Christiania.

8^h regelmäßiger schwacher Bogen durch den Flügel des Schwans. 9^h—10^h 20^m merkwürdig isoliertes Nordlicht welches in Form und Lage an den Donatischen Kometen 1858 um den 10 Oktober herum erinnerte, um 10^h aufgelöst. 10^h 10^m regelmäßiger, 15° hoher Bogen, 11^h strahlender Bogen.

Probably similar arcs have been observed in other countries from time to time. I have not had occasion to look into such observations, but will only draw attention to an arc observed by the Swedish astronomer Bohlin in Sweden, and which, according to visual observations,¹ seemed to be situated at a great altitude.

I may also draw attention to a high isolated arc observed in Scotland and southern Norway on 13 September 1933, but not photographed by my aurora stations because the weather was overcast at all stations. In a letter to me dated 27 September 1933, Professor Evershed writes as follows:

“... I was much interested to learn (from the Norwegian newspaper “Tidens Tegn”) that the very remarkable band of auroral light seen in Scotland on Sept. 13, 9.30—10.15 p. m., English Summer Time, was also seen in Norway (Stavanger). ... I observed the band carefully from the west coast of Scotland, lat. 56° 54', long. 5° 50' W and it appeared to me to be quite straight, passing a few degrees N of

¹ Karl Bohlin: Über eine sonderbare am 2 Januar 1897 beobachtete Nordlichterscheinung. Bihang till K. Svenska Vet.-Akad. Handlingar Band 24, Afd. 1, No. 5, Stockholm 1898.

zenith, and here it was about 15° in width. The edges were well defined, and the north edge passed through α and β Cassiopeiae and ξ Draconis, while the south edge just touched the Andromeda nebula . . ."

He asked me for observations from Norway and I was happy to be able to send him, among others, a very accurate one from Mr. Anton Røstad from Hornness in Setesdal, about 50 km north of Kristiansand. In a new letter of 14 October, Mr. Evershed writes:

" . . . Among numerous records from Scotland and England I have only succeeded in hearing of one good determination of its position among the stars, to compare with mine, but as this was 250 km to the south of my position at Arisaig, it gives a fairly good estimate of the height which I now find was 172 km . . . It was overhead along the 57th parallel in longitude 5° to 6° west . . ."

From the great height of 172 km, the arc seems to be of a kind similar to those measured before, but it showed phenomena not seen on these arcs. In fact, Mr. Røstad said, that at 9^h 55^m the arc changed; in the western sky in the form of a feeble curtain and near magnetic zenith a marked ray structure was visible. The rays moved from east to west with a velocity of about 10° per second; the arc did not reach the horizon in the east; it ceased at about 30° from that horizon. In the west, however, it went down to the horizon.

At 10^h the motion was as before but the arc reached only down to 45° over the horizon in the east.

At 10^h 20^m the arc had disappeared."

14. The Situation of the Arcs in Relation to the Earth's Shadow.

In earlier papers¹ I have drawn attention to the remarkable difference in height and spectrum of the auroral rays in sunshine and in the earth's shadow. In fact, the rays situated in the sunlit part of the atmosphere were stretching from about the boundary of the earth's shadow up to 800 till 1000 km, the rays in the dark part of the atmosphere, however, from about 100 km up to 300 till 400 km.

It is most interesting to see if the other aurora-forms, for instance, the arcs here mentioned, exhibit

similar effects. On Table IV, H_1 means the height of the earth's shadow near the auroral point and T is the distance from the projection of that point along the earth's surface to the point where the sun ray touches the earth (no account is taken of refraction).

It is seen that only some of the first pictures of the arc of the 29 September 1930 show an arc lying in sunshine, the other pictures give arcs in the earth's shadow. There seems to be a small tendency of the arc to rise if it occurs in the sunlit atmosphere, but the *high situation in all the other cases cannot be due to this*, the earth's shadow being too elevated to have any appreciable effect. Thus the high situation of the arc must *probably be due to the small penetration power of the corpuscles* which come from without, down in the earth's atmosphere.

15. The Geographical Situation of the Arcs.

From the map of the magnetic declination¹ elaborated by "Deutsche Seewarte," we have compared the direction of the arcs with the magnetic declination.

On Plate XV is seen *that the direction of the arcs is very nearly normal to the direction of the horizontal component of the terrestrial magnetic force at the earth's surface.*

From the material of aurora photographs collected from southern Norway 1911—1922 maps of all arcs were drawn, and, as seen from them, a similar tendency is preponderant for arcs over most of southern Norway. For more northern arcs, however, their directions often follow the small circles having their centres on the magnetic axis of the earth. (See especially the maps Nos. XVIII, XIX and XX.)

16. Summary.

Among the auroral phenomena observed and photographed in southern Norway during the last 25 years, there are some strange and most remarkable forms, which probably do not occur near the zones of maximum frequency of aurorae.

One of these forms is studied here, viz., homogeneous isolated arcs at an unusually high altitude.

¹ Carl Størmer: Sonnenbelichtete Nordlichtstrahlen, Zeitschrift für Geophysik 5, H. 5/2 and: Über die Probleme des Polarlichtes, Ergebnisse der kosmischen Physik, Akademische Verlagsgesellschaft, Leipzig 1931.

¹ Linien gleicher Misweisung für das Jahr 1931, Herausgegeben von der Marineleitung, Berlin 1932, IX.

² Carl Størmer: Resultats des mesures photogrammetriques des aurores boréales observées dans la Norvège meridionale de 1911 à 1922, Geofysiske Publikasjoner Vol. IV, No. 7.

Three cases, 29 September 1930, 10 March 1932 and 9 December 1933 were observed and photographed simultaneously from two or three stations. 35 pairs of corresponding pictures were measured and gave 262 determinations of height and situation.

The mean height of the lower border for the arcs on 29 September 1930, 10 March 1932 and 9 December 1933, was 195 km, 192 km and 197 km, and of the upper border, 232 km, 227 km and 216 km.

For the arc on 29 September 1930, it seems as if the part lying in the sunlit atmosphere

was higher than when the arc was in the earth's shadow.

The unusual height about the double of the mean height of arcs observed in southern Norway, suggests that the arcs were due to less penetrating corpuscles than the usual aurorae.

As to the geographical situation of the arcs, their direction is very nearly normal to the direction of the horizontal component of the terrestrial magnetic force at the earth's surface.

Table IV.

Picture No.	Point No.	Time MET	Base	u_1	u_2	p	h	a	H	D	H_1	T
<i>High Homogeneous Auroral Arc on 29 September 1930.</i>												
1 (Plate I)	1	20. 0. 6	<i>C—O</i>	58.5	62.4	3.9	44.6	56.0	254	244		
	2	-	-	58.2	61.7	3.5	40.1	59.4	259	290		
	3	-	-	58.1	61.4	3.3	37.1	61.5	260	320		
	4	-	-	58.2	61.4	3.2	34.1	63.3	253	345	190	1540
	5	-	-	56.0	60.2	4.2	43.1	53.1	225	229	218	1650
	6	-	-	55.9	59.9	4.0	38.9	56.8	218	256	211	
	7	-	-	56.1	59.9	3.8	36.1	59.2	215	279	205	
	8	-	-	56.35	60.0	3.65	33.4	61.3	211	300	200	
2 (Plate I)	1	20. 1.24	<i>C—O</i>	59.6	63.6	4.0	43.8	58.2	248	245		
	2	-	-	59.3	62.9	3.6	39.0	61.8	250	289		
	3	-	-	59.3	62.7	3.4	35.0	64.4	245	325		
	4	-	-	59.5	62.7	3.2	31.3	66.6	239	361		
	5	-	-	60.0	63.0	3.0	29.0	68.0	237	390		
	6	-	-	60.6	63.5	2.9	26.4	69.5	229	419	175	1480
	7	-	-	57.2	61.6	4.4	41.1	56.7	210	229	222	1655
	8	-	-	57.0	61.2	4.2	37.2	59.8	204	255		
	9	-	-	57.2	61.1	3.9	33.2	62.7	200	285		
	10	-	-	57.7	61.2	3.5	29.6	65.1	202	332		
	11	-	-	58.4	61.5	3.1	26.7	66.8	210	383		
3 (Plate I)	1	20. 2. 6	<i>C—O</i>	62.9	67.6	4.7	60.7	34.3	270	145	249	1758
	2	-	-	62.1	66.5	4.4	57.2	43.3	277	170		
	3	-	-	61.5	65.7	4.2	53.7	49.5	277	193		
	4	-	-	61.0	65.1	4.1	48.5	56.0	265	222	223	1665
	5	-	-	59.5	66.7	7.2	57.9	30.3	170	103	254	1770
	6	-	-	58.6	65.4	6.8	54.5	39.2	172	119		
	7	-	-	58.0	64.6	6.6	51.0	45.7	169	132		
	8	-	-	57.8	64.0	6.2	46.5	52.3	168	153	236	1710
4 (Plate II)	1	20. 2.53	<i>C—O</i>	64.3	70.0	5.7	61.0	39.2	226	121		
	2	-	-	62.9	68.3	5.4	56.6	47.2	227	143		
	3	-	-	62.0	67.1	5.1	52.2	53.0	227	169	238	1715
	4	-	-	61.6	67.6	6.0	58.8	36.5	209	121	254	1770
	5	-	-	60.6	66.2	5.6	55.0	44.2	213	142		
	6	-	-	59.6	64.9	5.3	50.6	50.2	210	165		
5 (Plate II)	1	20. 3.44	<i>C—O</i>	62.2	67.0	4.8	41.8	64.5	204	218	224	1670
	2	-	-	62.0	66.5	4.5	38.6	66.2	204	242		
	3	-	-	62.0	66.0	4.0	33.5	68.6	204	291		
	4	-	-	62.4	66.0	3.6	28.2	71.0	199	340	196	1560
	5	-	-	59.0	63.1	4.1	40.4	60.7	225	251	222	1660
	6	-	-	59.0	62.8	3.8	37.4	62.7	227	280		
	7	-	-	59.3	62.9	3.6	32.6	65.7	216	316	206	1600
6 (Plate II)	1	20. 4.25	<i>C—O</i>	63.1	67.0	3.9	30.4	71.5	195	312	203	1590
	2	-	-	63.0	66.6	3.6	27.7	72.4	195	343		
	3	-	-	63.2	66.5	3.3	25.8	73.1	199	379		
	4	-	-	63.4	66.5	3.1	24.0	73.7	200	412		
	5	-	-	63.6	66.5	2.9	22.2	74.3	202	445		
	6	-	-	63.9	66.6	2.7	20.5	75.0	205	485	167	1440
	7	-	-	60.9	64.1	3.2	30.2	68.9	233	370	195	1560
	8	-	-	61.0	64.0	3.0	27.3	70.2	229	403		
	9	-	-	61.3	64.1	2.8	24.9	71.1	228	441		
	10	-	-	61.7	64.4	2.7	22.5	72.1	219	470	173	1470
13 (Plate III)	1	20.14. 9	<i>C—O</i>	59.9	65.5	5.6	59.5	24.0	221	125		
	2	-	-	58.9	64.5	5.6	56.8	32.1	211	137		
	3	-	-	58.2	63.7	5.5	53.8	39.5	209	146		
	4	-	-	58.0	62.9	4.9	50.4	45.8	221	176		
	5	-	-	57.8	62.7	4.9	46.8	50.8	210	188	282	1865
	6	-	-	56.9	63.3	6.4	56.7	22.2	185	119	308	1950
	7	-	-	55.8	62.1	6.3	54.0	30.3	180	125		
	8	-	-	55.3	61.3	6.0	51.5	36.7	182	140		
	9	-	-	54.9	60.7	5.8	48.1	43.0	178	153		
	10	-	-	55.1	60.6	5.5	44.9	48.2	175	173		

Table IV (continued).

Picture No.	Point No.	Time MET	Base	u_1	u_2	p	h	a	H	D	H_1	T	
14 (Plate III)	1	20.15.50	C-O	56.9	61.2	4.3	43.4	54.1	224	225	280	1860	
	2	-	-	57.3	61.2	3.9	39.5	58.6	229	262			
	3	-	-	58.0	61.6	3.6	36.1	62.0	231	300	259	1790	
	4	-	-	54.1	59.2	5.1	41.5	51.6	179	192	287	1880	
	5	-	-	54.6	59.3	4.7	38.0	55.9	181	222			
	6	-	-	55.2	59.6	4.4	34.8	59.0	180	246			
	7	-	-	56.0	60.1	4.1	31.2	62.0	178	277	263	1800	
15 (Plates III and XVI)	1	20.17.41	C-O	70.3	76.4	6.1	62.1	360-30.9	222	113	355	2080	
	2	-	-	67.8	74.0	6.2	64.0	360-17.9	221	105			
	3	-	-	65.5	71.7	6.2	64.4	360-4.0	219	100			
	4	-	-	63.6	69.6	6.0	63.7	9.0	220	106			
	5	-	-	62.0	67.8	5.8	61.8	20.4	222	115	326	2000	
	6	-	-	66.5	73.4	6.9	59.5	360-25.5	181	103			
	7	-	-	63.9	70.8	6.9	60.6	360-13.5	188	103			
	8	-	-	61.7	68.4	6.7	60.8	360-1.6	190	103			
	9	-	-	59.9	66.6	6.7	59.9	9.6	186	106			
	10	-	-	58.4	64.8	6.4	58.1	19.7	190	115	326	2000	
16 (Plates IV and XVI)	1	20.19.37	C-O	61.5	67.2	5.7	60.8	23.8	225	120	333	2018	
	2	-	-	60.6	66.1	5.5	58.6	32.0	225	133			
	3	-	-	59.7	65.0	5.3	55.4	39.8	222	146			
	4	-	-	59.3	64.3	5.0	52.7	45.6	226	166			
	5	-	-	59.0	63.7	4.7	48.8	51.5	228	191			
	6	-	-	58.7	63.2	4.5	45.6	55.2	225	212	297	1910	
	7	-	-	58.6	65.3	6.7	58.0	22.6	181	110	333	2018	
	8	-	-	57.5	64.1	6.6	55.8	29.8	179	118			
	9	-	-	56.7	63.0	6.3	53.0	37.2	180	131			
	10	-	-	56.3	62.2	5.9	50.3	42.5	183	146			
	11	-	-	56.0	61.6	5.6	46.8	48.2	180	163			
	12	-	-	56.0	61.3	5.3	44.0	52.2	182	181	304	1930	
16 (Plate IV)	1	-	O-T	180-66.8	180-53.2	13.6	66.7	26.5	229	97	337	2030	
	2	-	-	180-65.1	180-51.9	13.2	64.0	36.5	229	108			
	3	-	-	180-63.3	180-50.7	12.6	60.3	45.5	228	125			
	4	-	-	180-62.0	180-49.8	12.2	56.7	51.5	225	142			
	7	-	-	180-64.9	180-49.6	15.3	64.8	25.3	194	88	337	2030	
	8	-	-	180-63.1	180-48.3	14.8	62.2	34.5	193	98			
	9	-	-	180-61.2	180-47.4	13.8	58.6	43.2	194	115			
	10	-	-	180-60.0	180-46.8	13.2	55.2	49.0	195	131			
	17 (Plates IV and XVI)	1	20.21.25	C-O	59.2	63.6	4.4	46.3	54.9	234	214		
		2	-	-	59.3	63.4	4.1	40.7	60.6	227	250		
3		-	-	59.7	63.4	3.7	36.4	64.3	231	296	278	1850	
4		-	-	56.7	61.6	4.9	44.8	52.1	200	194	308	1950	
5		-	-	56.8	61.4	4.6	39.3	57.8	195	226			
6		-	-	57.3	61.5	4.2	34.9	61.7	193	260			
17 (Plate V)	7	-	O-T	180-63.9	180-50.8	13.1	61.9	43.0	225	116	333	2018	
	8	-	-	180-62.2	180-48.0	14.2	60.3	41.2	194	107			

High Homogeneous Auroral Arc on 10 March 1932.

2 (Plate V)	1	21.26.15	C-K	27.3	30.1	2.8	16.3	87.8	220	622		
	2	-	-	25.5	27.8	2.3	12.4	88.1	205	715		
	3	-	-	24.6	26.45	1.85	10.1	88.3	221	866	337	
	4	-	-	29.6	33.7	4.1	17.2	90.0	168	472	450	
	5	-	-	27.5	30.8	3.3	13.4	90.0	160	553		
	6	-	-	26.4	29.1	2.7	10.8	89.8	162	651		
3 (Plate V)	1	21.28.9	C-K	31.7	36.1	4.4	25.9	84.7	233	436		
	2	-	-	29.5	33.3	3.8	22.1	85.7	223	486		
	3	-	-	28.3	31.6	3.3	19.7	86.3	224	541		
	4	-	-	27.3	30.3	3.0	17.6	86.7	219	581	433	
	5	-	-	33.1	39.3	6.2	25.2	88.0	173	339	507	
	6	-	-	31.1	35.7	4.6	21.9	88.3	192	430		
	7	-	-	29.9	33.9	4.0	19.5	88.7	192	478		
	8	-	-	28.9	32.4	3.5	17.4	88.9	193	531		

Table IV (continued).

Picture No.	Point No.	Time MET	Base	u_1	u_2	p	h	a	H	D	H_1	T
4 (Plate VI)	1	21.29.47	C-K	28.5	32.4	3.9	24.2	81.2	227	452		
	2	-	-	26.7	30.0	3.3	21.2	82.1	225	510		
	3	-	-	25.3	28.3	3.0	18.4	83.1	212	545	462	
	4	-	-	29.5	34.3	4.8	23.6	83.7	188	392	507	
	5	-	-	28.0	32.1	4.1	21.0	84.3	190	441		
	6	-	-	26.8	30.2	3.4	18.5	85.2	195	509		
5 (Plate VI)	1	21.31.45	C-K	30.7	35.2	4.5	27.4	80.0	234	412		
	2	-	-	27.8	31.5	3.7	23.4	81.0	228	470		
	3	-	-	25.5	28.5	3.0	19.8	81.9	226	541	475	
	4	-	-	30.5	35.6	5.1	25.3	83.1	194	377	523	
	5	-	-	28.1	32.3	4.2	21.8	83.6	191	430		
	6	-	-	26.0	29.5	3.5	18.5	84.1	186	486		
6 (Plate VI)	1	21.34. 4	C-K	27.5	31.2	3.7	23.3	80.5	226	468		
	2	-	-	25.7	29.0	3.3	20.6	81.0	215	497		
	3	-	-	24.0	26.7	2.7	17.9	81.5	220	578	480	
	4	-	-	29.3	33.9	4.6	24.0	82.9	195	402	528	
	5	-	-	27.2	31.2	4.0	21.0	83.1	190	440		
	6	-	-	25.3	28.7	3.4	18.0	83.4	183	490		
7 (Plate VII)	1	21.37.43	C-K	21.5	23.1	1.6	13.0	82.8	268	860		
	2	-	-	20.5	22.0	1.5	9.5	83.8	220	892		
	3	-	-	20.4	21.8	1.4	6.8	84.7	194	960	380	
	4	-	-	22.6	24.8	2.2	12.5	84.5	192	678	459	
	5	-	-	21.6	23.4	1.8	9.4	85.1	184	786		
	6	-	-	21.4	22.9	1.5	7.5	85.6	196	930		
8 (Plate VII)	1	21.40.15	C-K	21.4	22.8	1.4	12.0	83.4	292	967		
	2	-	-	20.7	22.1	1.4	8.9	84.4	230	957		
	3	-	-	20.7	21.9	1.2	5.7	85.5	218	1117	344	
	4	-	-	21.5	22.2	1.7	9.3	85.2	185	796	436	
	5	-	-	21.5	22.9	1.4	7.1	85.9	209	997		
	6	-	-	21.4	22.8	1.4	6.0	86.6	189	998		
9 (Plate VII)	1	21.44.11	C-K	21.7	23.3	1.6	9.9	85.2	222	879		
	2	-	-	21.6	23.0	1.4	7.9	86.0	225	997		
	3	-	-	21.8	23.0	1.2	5.8	86.7	235	1167	347	
	4	-	-	23.5	25.7	2.2	10.6	86.7	176	704	477	
	5	-	-	23.0	24.8	1.8	8.4	87.1	184	837		
	6	-	-	22.8	24.3	1.5	6.3	87.6	192	988		
10 (Plate VIII)	1	21.48. 0	C-K	22.1	23.8	1.7	11.0	85.0	227	840		
	2	-	-	21.95	23.4	1.45	8.0	86.2	221	979		
	3	-	-	22.3	23.55	1.25	5.0	87.4	213	1151	365	
	4	-	-	24.2	26.2	2.0	12.0	87.0	221	779	475	
	5	-	-	23.3	25.0	1.7	8.6	87.5	203	890		
	6	-	-	23.5	24.9	1.4	5.7	88.5	207	1082		
11 (Plates VIII and XVII)	1	21.51.21	C-K	29.3	34.3	5.0	25.4	80.9	192	372		
	2	-	-	26.0	29.5	3.5	20.8	81.7	205	478		
	3	-	-	23.8	26.3	2.5	17.0	82.5	225	612		
	4	-	-	22.0	23.8	1.8	12.9	83.5	234	780		
	5	-	-	21.3	22.85	1.55	9.9	84.5	227	895	470	
	7	-	-	30.0	35.3	5.3	23.1	85.2	172	368	628	
	8	-	-	27.1	31.0	3.9	19.1	85.2	179	457		
	9	-	-	24.7	27.3	2.6	15.0	85.5	200	618		
	10	-	-	22.7	24.6	1.9	10.3	85.9	195	782		
	13 (Plates VIII and XVII)	1	21.58.53	C-K	28.0	32.0	4.0	23.3	81.7	212	441	
2	-	-	23.9	26.6	2.7	16.9	82.9	209	579			
3	-	-	22.0	23.9	1.9	13.0	83.6	227	754			
4	-	-	21.0	22.5	1.5	8.9	84.7	216	914			
5	-	-	21.1	22.5	1.4	6.0	86.0	186	986			
6	-	-	28.0	32.6	4.6	20.3	85.4	165	401	657		
7	-	-	24.5	27.7	3.2	14.7	85.5	161	518	477		
8	-	-	22.9	24.9	2.0	11.0	86.0	196	751			
9	-	-	22.3	24.0	1.7	6.9	86.9	173	875			

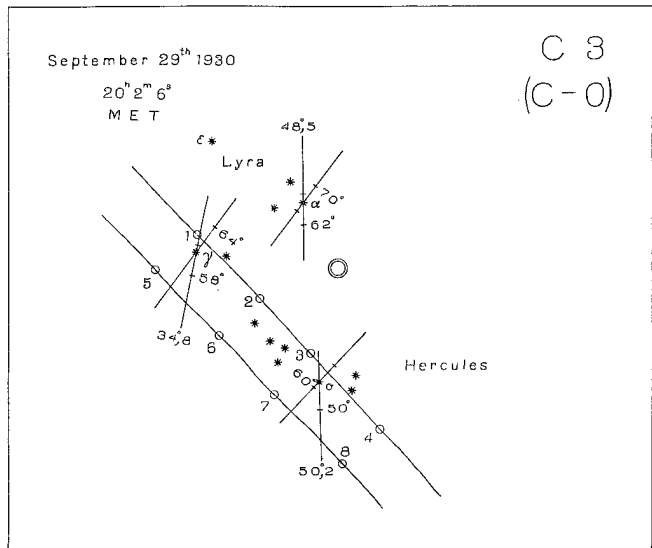
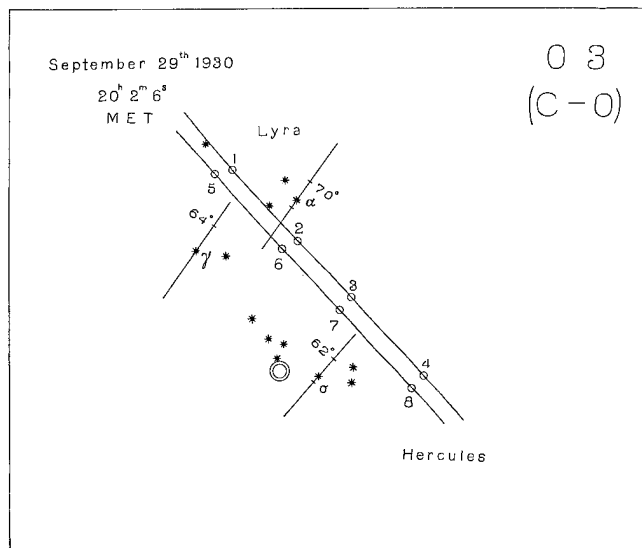
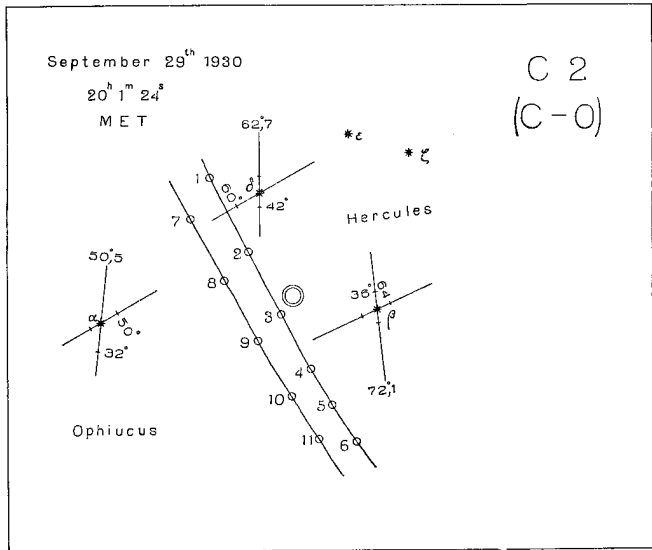
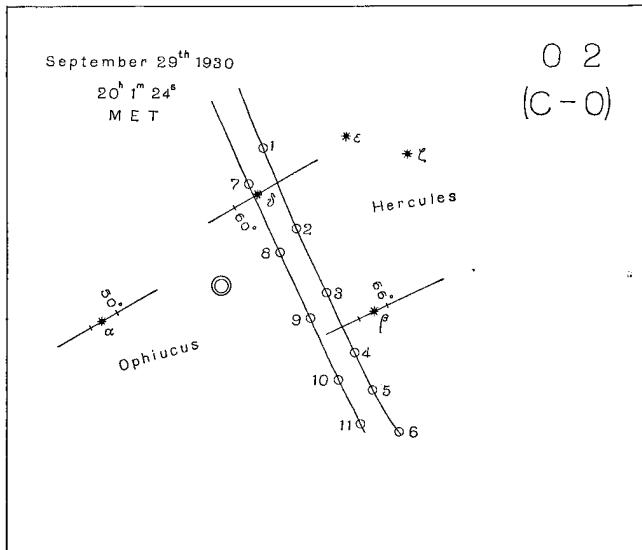
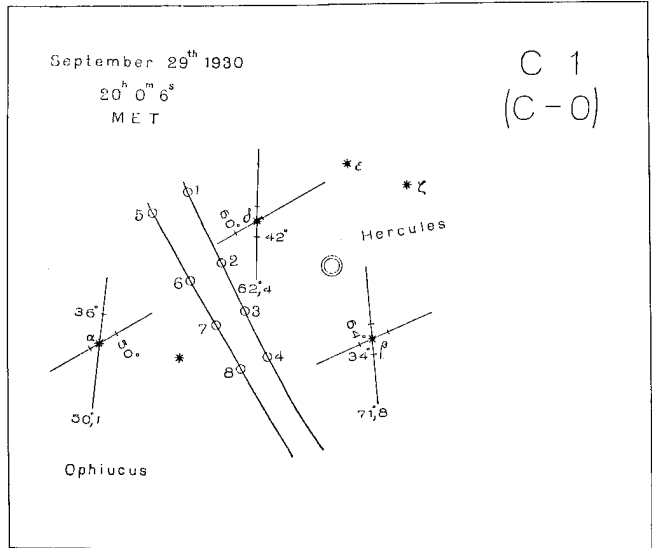
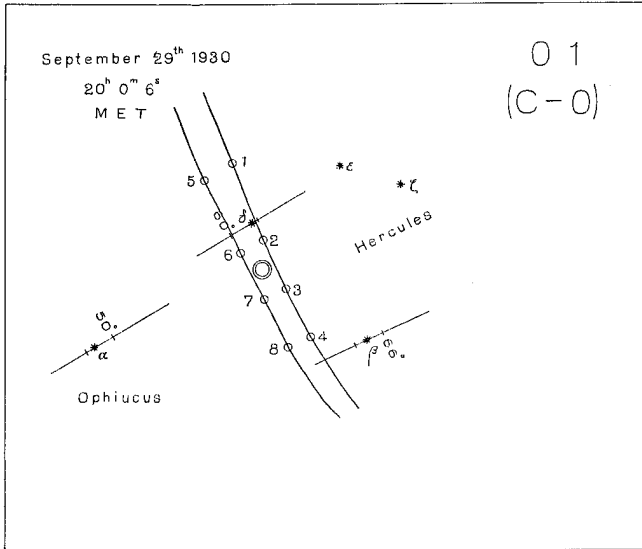
Table IV (continued).

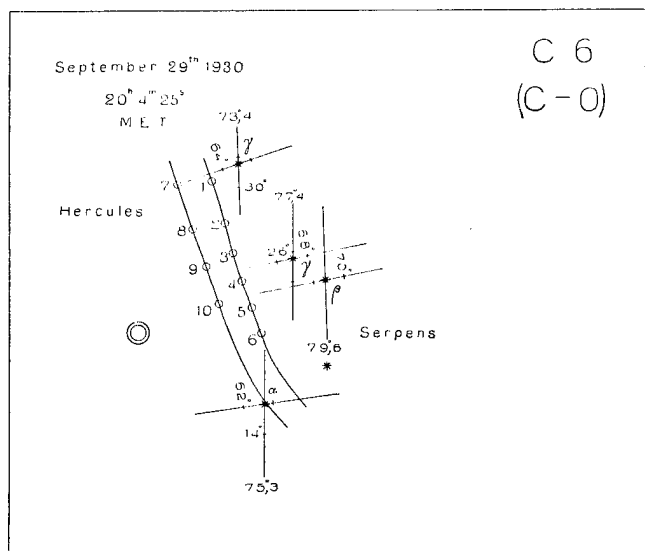
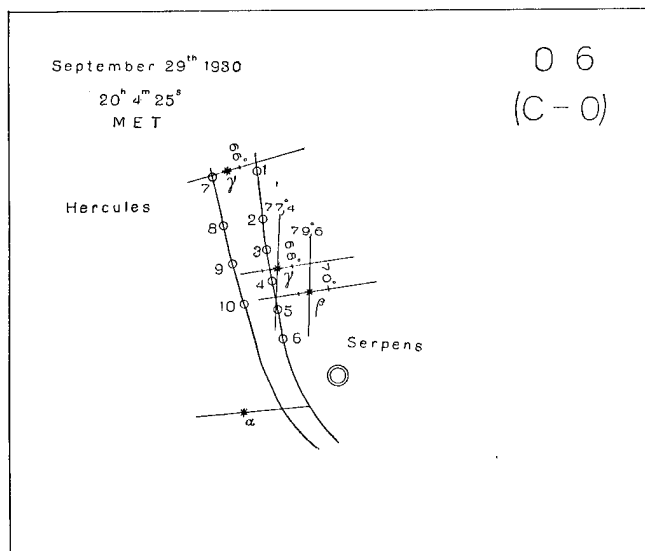
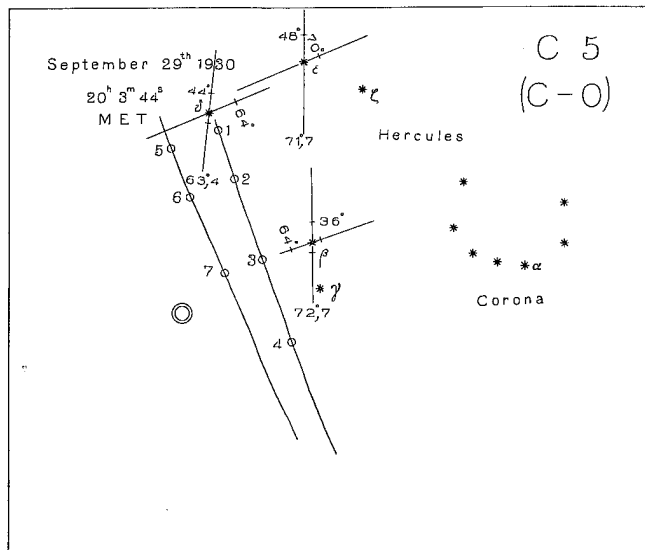
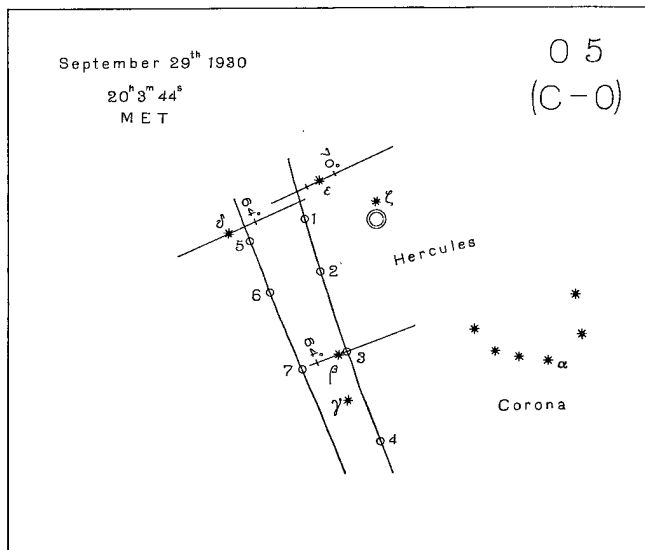
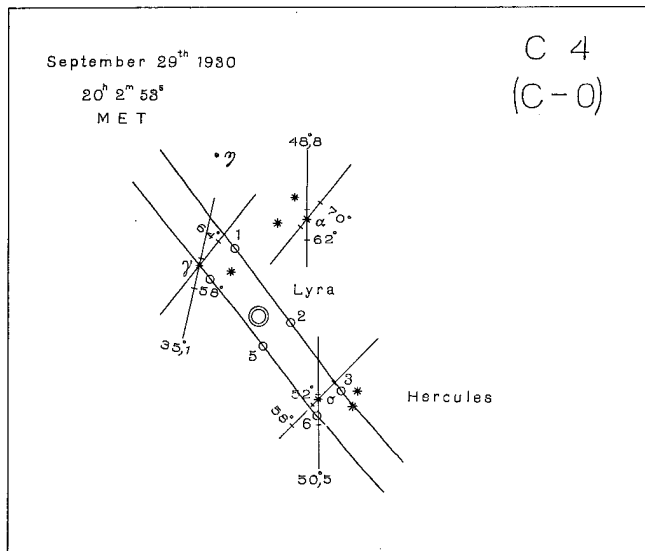
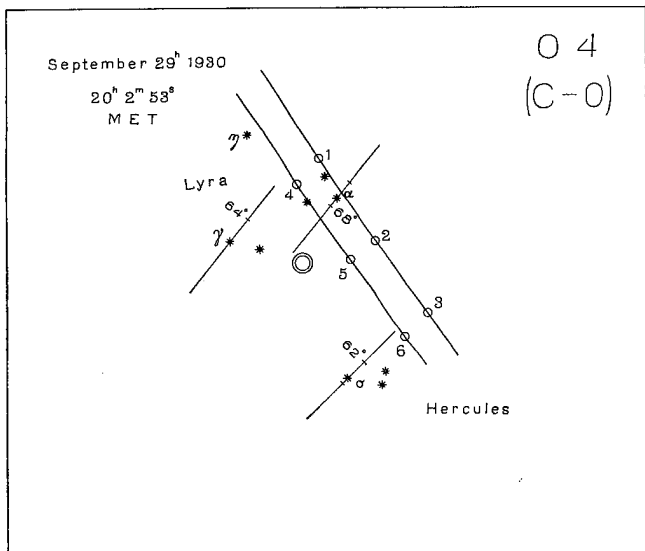
Picture No.	Point No.	Time MET	Base	u_1	u_2	p	h	a	H	D	H_1	T
14 (Plates IX and XVII)	1	22. 1.33	<i>C-K</i>	26.7	30.4	3.7	22.0	81.3	210	462		
	2	-	-	23.6	26.1	2.5	17.1	82.3	224	608		
	3	-	-	22.0	23.8	1.8	13.0	83.4	235	781		
	4	-	-	21.2	22.7	1.5	10.0	84.3	237	918		
	5	-	-	21.1	22.3	1.2	7.0	85.3	249	1128	452	
	6	-	-	30.0	35.3	5.3	24.0	84.3	178	365	691	
	7	-	-	25.9	29.4	3.5	18.0	84.5	182	488		
	8	-	-	23.8	26.2	2.4	14.0	84.9	200	650		
	9	-	-	22.7	24.7	2.0	11.0	85.4	195	748		
	10	-	-	22.2	23.8	1.6	8.0	86.1	200	907		
15 (Plate IX)	1	22. 3.46	<i>C-K</i>	44.0	53.4	9.4	43.1	76.0	225	228		
	2	-	-	40.6	48.8	8.2	39.4	76.7	224	258		
	3	-	-	38.2	46.0	7.8	36.7	77.3	214	270		
	4	-	-	35.5	42.6	7.1	33.7	78.0	206	290		
	5	-	-	46.0	55.6	9.6	42.6	85.0	220	228	744	
	6	-	-	42.9	51.6	8.7	39.1	85.0	218	255		
	7	-	-	39.3	47.4	8.1	35.0	84.9	201	271		
	8	-	-	37.8	45.7	7.9	33.0	85.1	192	280	726	
16 (Plate IX)	1	22. 6.23	<i>C-K</i>	180-78.4	180-64.3	14.1	78.4	180+66.0	235	47	842	
	2	-	-	180-75.4	180-61.2	14.2	75.1	180+70.5	225	58		
	3	-	-	180-72.1	180-58.8	13.3	72.0	180+73.0	230	73	853	
	4	-	-	180-81.4	180-67.8	13.6	78.9	360-76.5	253	47		
	5	-	-	180-77.8	180-65.1	12.7	75.1	360-80.5	260	67		
	6	-	-	180-74.2	180-62.2	12.0	71.2	360-83.0	263	88		
17 (Plate X)	1	22. 9. 4	<i>C-K</i>	29.3	33.5	4.2	25.8	79.7	228	426		
	2	-	-	25.7	29.0	3.3	21.1	80.7	218	496		
	3	-	-	22.8	25.2	2.4	16.1	82.0	216	617		
	4	-	-	20.75	22.4	1.65	11.1	83.5	225	823		
	5	-	-	20.5	21.8	1.3	7.1	85.0	218	1024	526	
	6	-	-	29.6	34.9	5.3	24.0	83.5	175	360	735	
	7	-	-	26.0	29.8	3.8	19.0	83.7	175	450		
	8	-	-	23.1	25.8	2.7	14.0	84.3	172	570		
	9	-	-	22.0	24.2	2.2	11.1	84.8	171	668		
	10	-	-	21.4	23.1	1.7	8.0	85.6	180	838		
23 (Plate X)	1	22.21.44	<i>C-O</i>	67.2	71.0	3.8	38.0	73.5	245	296		
	2	-	-	67.2	70.7	3.5	33.8	74.7	244	338		
	3	-	-	67.3	70.5	3.2	30.2	75.9	245	387		
	4	-	-	67.5	70.5	3.0	26.7	76.8	235	425	816	
	5	-	-	70.1	75.1	5.0	38.0	77.2	191	232	861	
	6	-	-	70.2	74.8	4.6	34.5	78.2	192	263		
	7	-	-	70.4	74.7	4.3	30.7	79.3	186	295		
	8	-	-	70.5	74.5	4.0	27.3	80.2	182	327		
24 (Plate X)	1	22.25.16	<i>C-O</i>	74.1	80.3	6.2	74.0	10.0	240	66		
	2	-	-	72.9	79.3	6.4	72.8	20.0	231	70		
	3	-	-	71.9	78.5	6.6	71.3	28.0	220	72		
	4	-	-	76.5	83.6	7.1	76.5	17.5	213	52	1001	
	5	-	-	75.9	83.0	7.1	75.6	25.5	212	54		
	6	-	-	74.9	82.0	7.1	73.9	33.5	210	60	993	
<i>High Homogeneous Auroral Arc of 9 December 1933.</i>												
66 (Plate XI)	1	22.59.53	<i>K-T</i>	180-37.9	180-31.5	6.4	23.3	78.9	210	438	3470	
	2	-	-	180-36.1	180-31.5	4.6	15.2	81.3	213	638		
	3	-	-	180-36.1	180-32.1	4.0	11.9	82.4	213	758		
	4	-	-	180-36.2	180-32.5	3.7	9.6	83.1	205	837	3100	
	5	-	-	180-36.2	180-30.2	6.0	22.2	77.3	207	455		
	6	-	-	180-34.7	180-30.1	4.6	14.7	79.9	197	615		
	7	-	-	180-34.7	180-30.7	4.0	11.5	80.9	196	730		
	8	-	-	180-34.9	180-31.1	3.8	9.3	81.7	182	785		
67 (Plates XI and XVIII)	1	23. 2. 4	<i>K-T</i>	180-37.9	180-31.8	6.1	23.3	79.9	223	463		
	2	-	-	180-36.5	180-31.7	4.8	16.5	81.3	218	612		
	3	-	-	180-36.3	180-32.1	4.2	13.1	82.3	217	722		
	4	-	-	180-36.3	180-32.5	3.8	10.8	83.1	214	812	3180	
	5	-	-	180-36.3	180-30.2	6.1	22.5	77.5	205	446	3520	
	6	-	-	180-35.0	180-30.2	4.8	15.9	79.8	201	520		
	7	-	-	180-35.0	180-30.7	4.3	12.7	81.0	195	679		
	8	-	-	180-35.2	180-31.3	3.9	10.5	81.9	195	769		

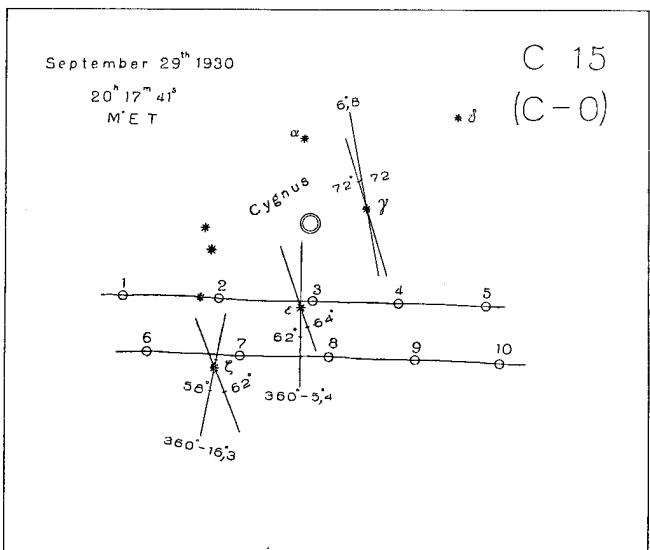
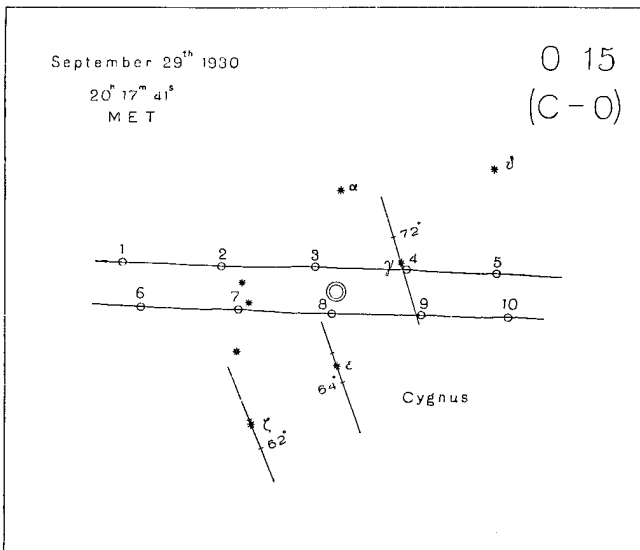
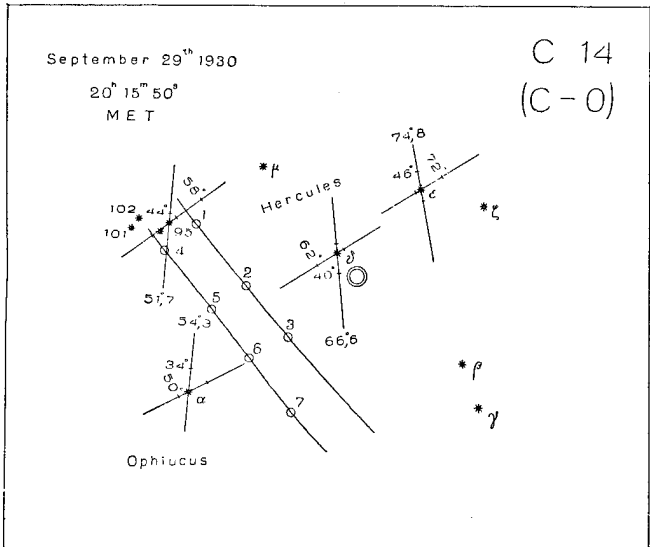
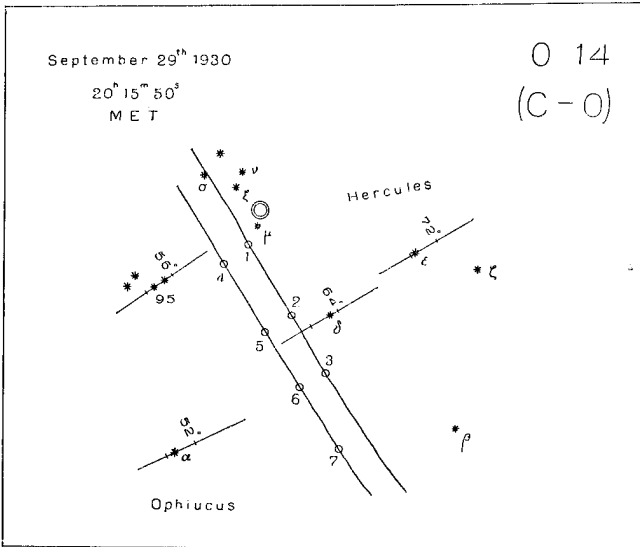
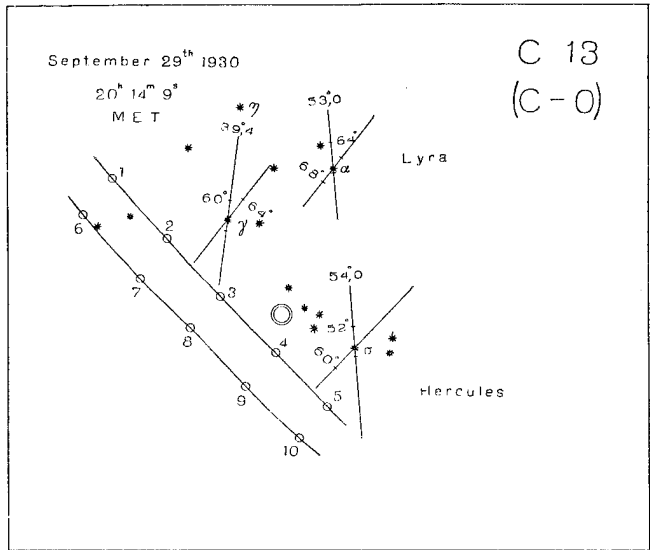
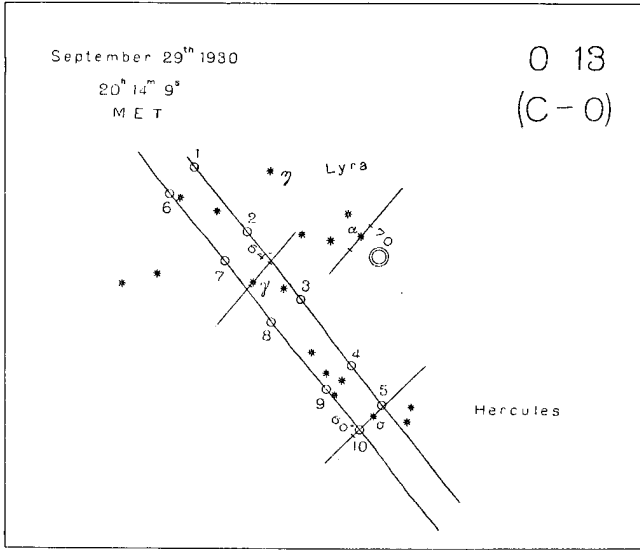
Table IV (continued).

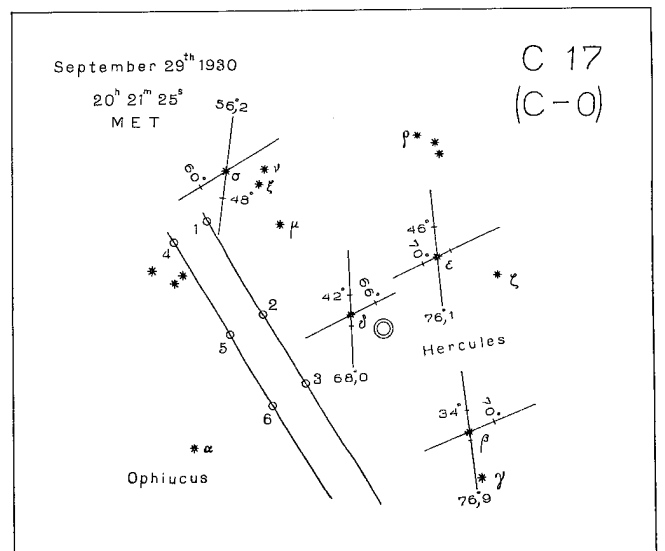
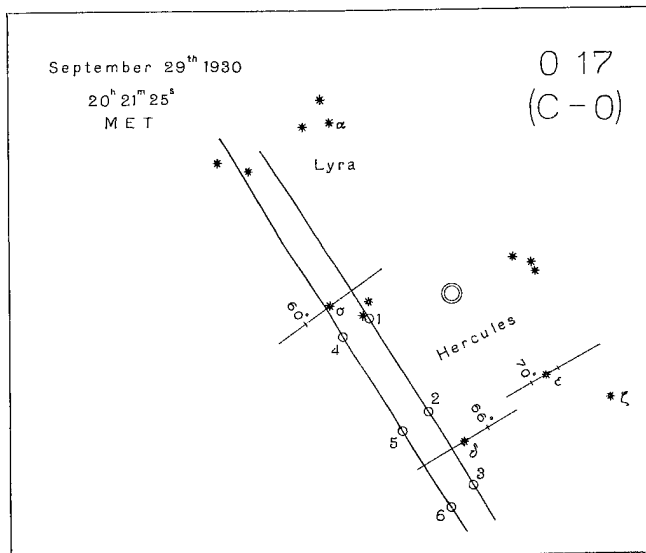
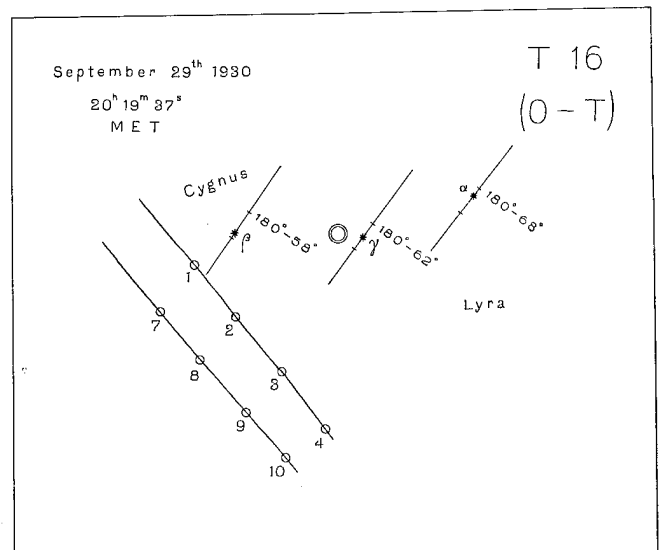
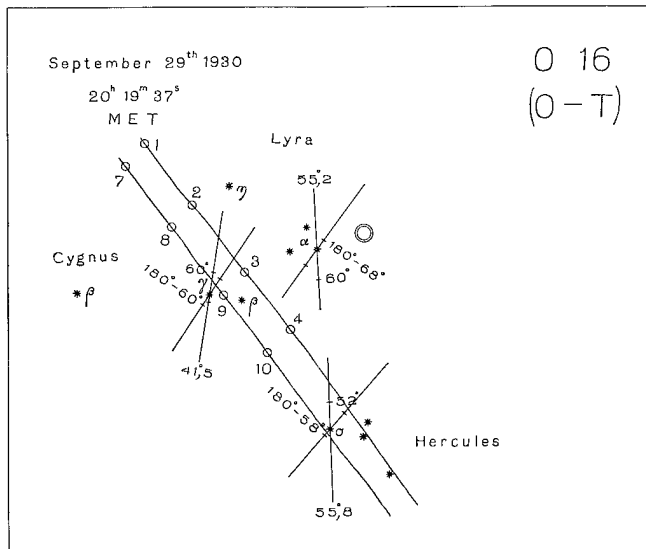
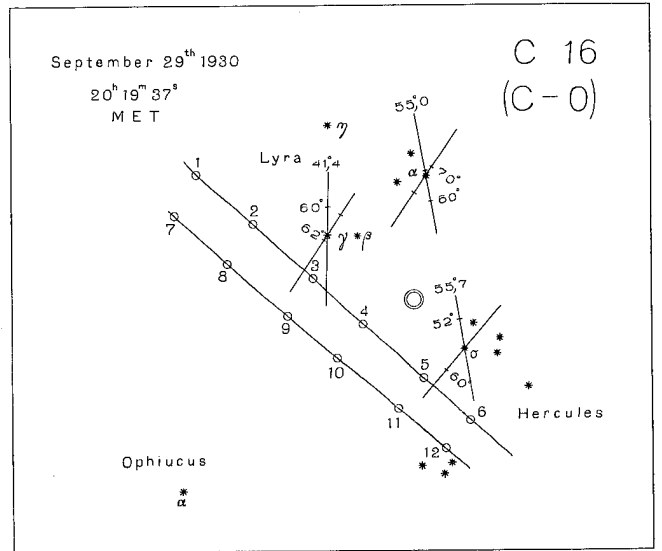
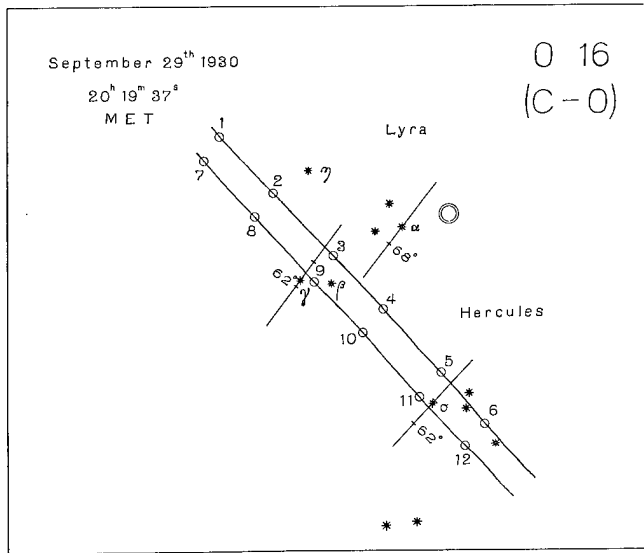
Picture No.	Point No.	Time MET	Base	u_1	u_2	p	h	a	H	D	H_1	T
68 (Plates IX and XVIII)	1	23. 4.13	<i>K-T</i>	180-39.0	180-31.9	7.1	26.3	78.3	212	392	3600	
	2	-	-	180-36.7	180-31.3	5.4	18.8	80.5	211	535		
	3	-	-	180-36.5	180-32.3	4.2	13.2	82.6	219	723		
	4	-	-	180-37.0	180-33.4	3.6	9.8	84.0	222	880	3150	
	5	-	-	180-36.5	180-29.9	6.6	24.7	76.1	203	402		
	6	-	-	180-35.0	180-29.5	5.5	18.0	78.8	189	500		
	7	-	-	180-35.0	180-30.7	4.3	12.8	81.1	195	677		
	8	-	-	180-35.6	180-31.9	3.7	9.5	82.6	198	826		
69 (Plate XII)	1	23. 6.25	<i>K-Li</i>	180-65.3	180-48.5	16.8	27.4	78.3	208	370		
	2	-	-	180-65.3	180-50.2	15.1	23.9	79.2	213	433		
	3	-	-	180-62.7	180-46.2	16.5	25.1	76.0	190	371		
	4	-	-	180-63.2	180-49.3	13.9	20.0	77.6	196	477		
	5	-	-	180-63.5	180-50.3	13.2	18.1	78.3	195	517		
70 (Plate XII)	1	23. 8.10	<i>K-Li</i>	180-65.1	180-52.6	12.5	18.3	80.0	216	560		
	2	-	-	180-66.0	180-56.4	9.6	13.1	81.6	237	778		
	3	-	-	180-63.2	180-50.0	13.2	18.0	78.0	192	512		
	4	-	-	180-64.2	180-54.1	10.5	13.0	80.1	204	697		
	5	-	-	180-66.1	180-56.9	9.2	9.5	81.9	200	831		
	6	-	-	180-66.5	180-57.7	8.8	8.5	82.3	199	878		

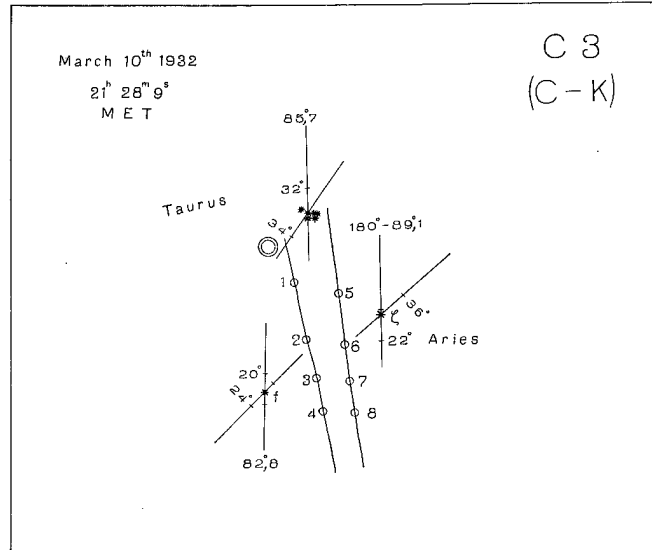
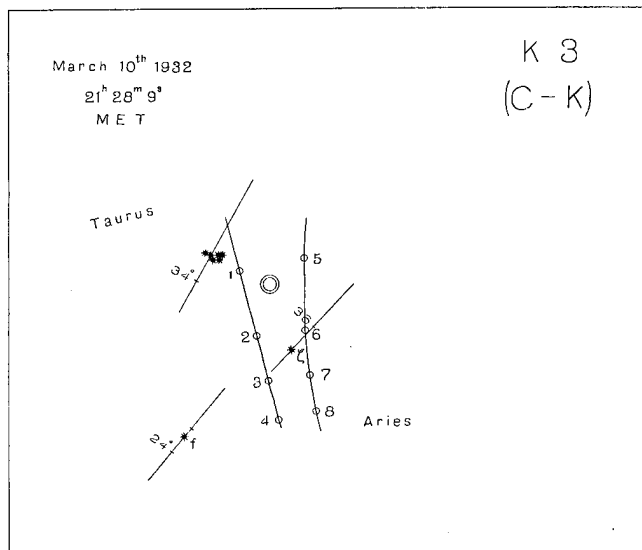
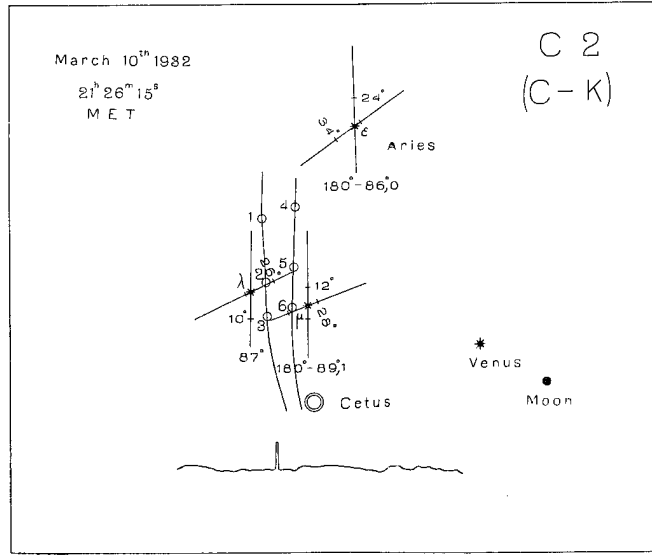
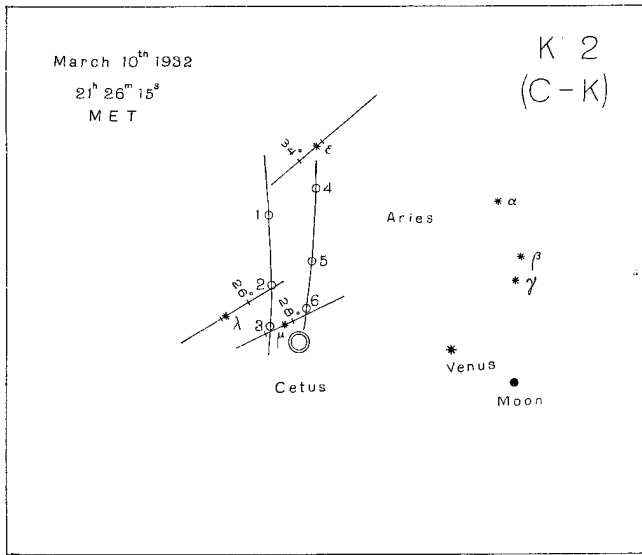
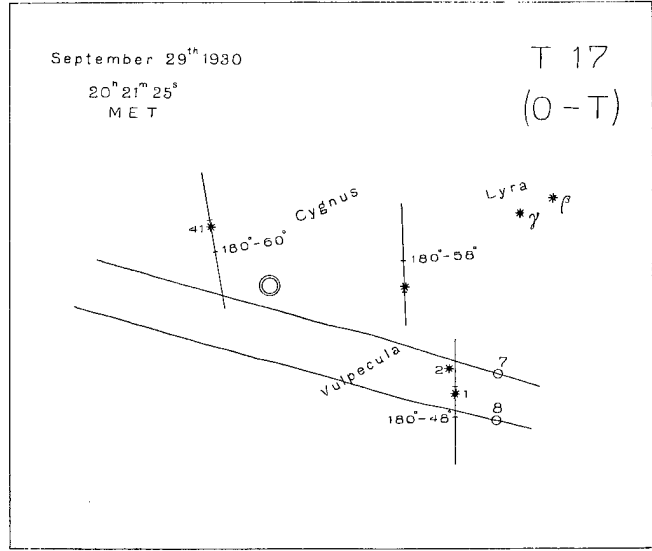
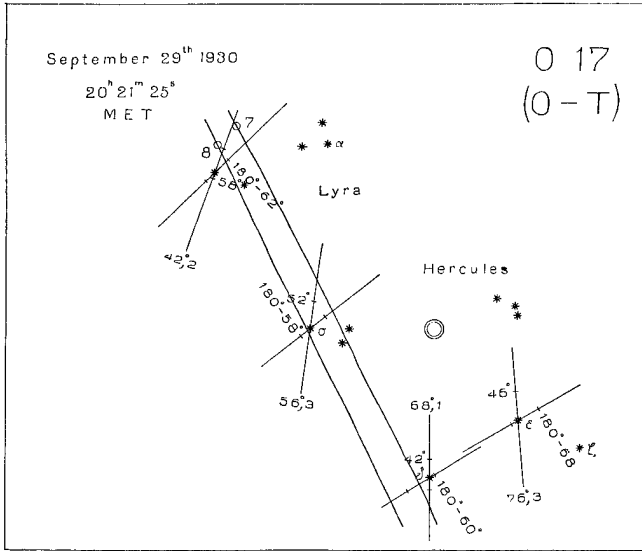
Printed, December 30th, 1935.

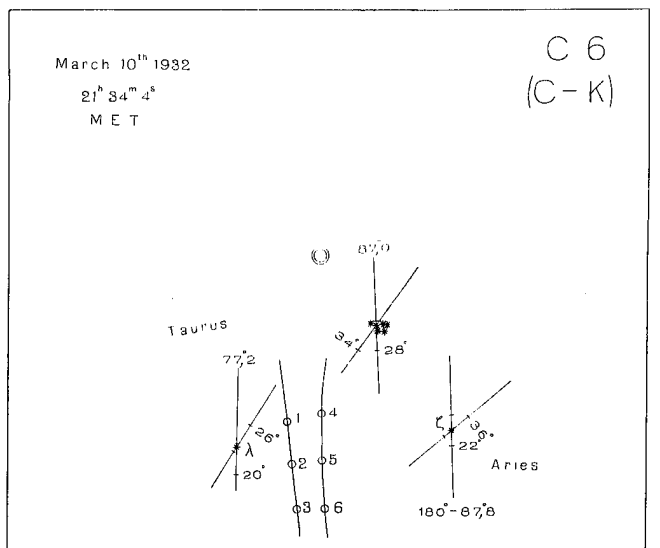
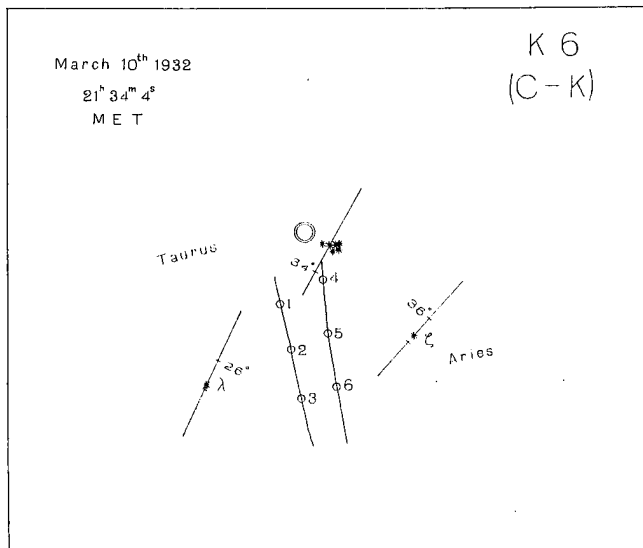
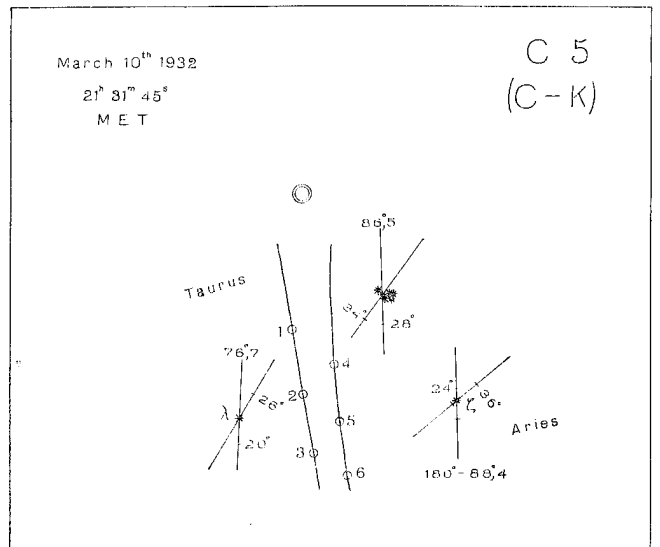
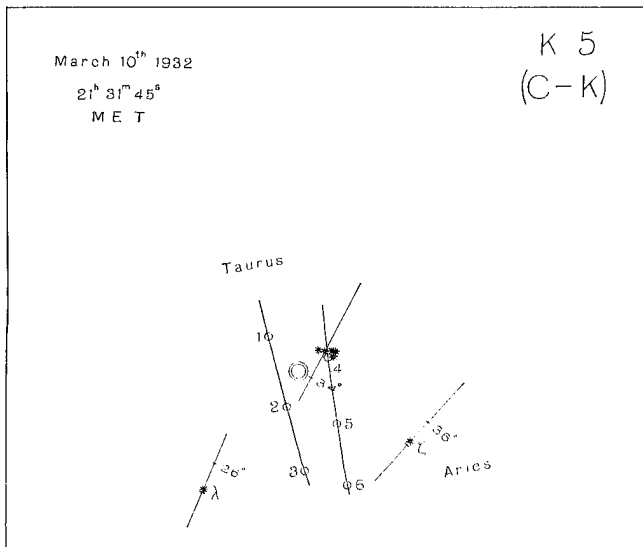
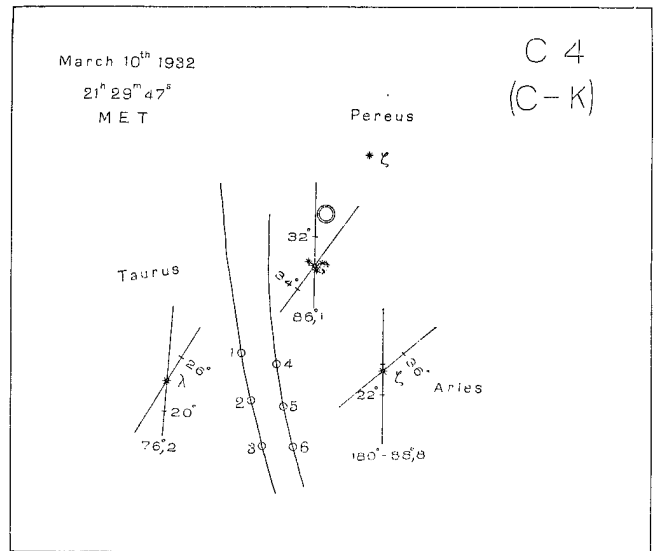
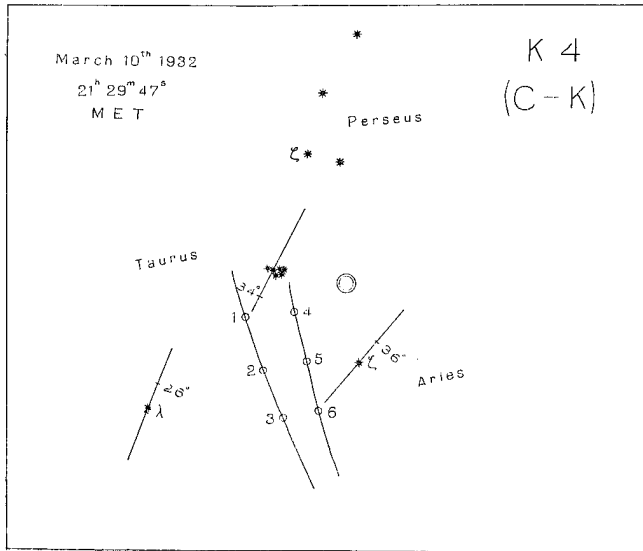


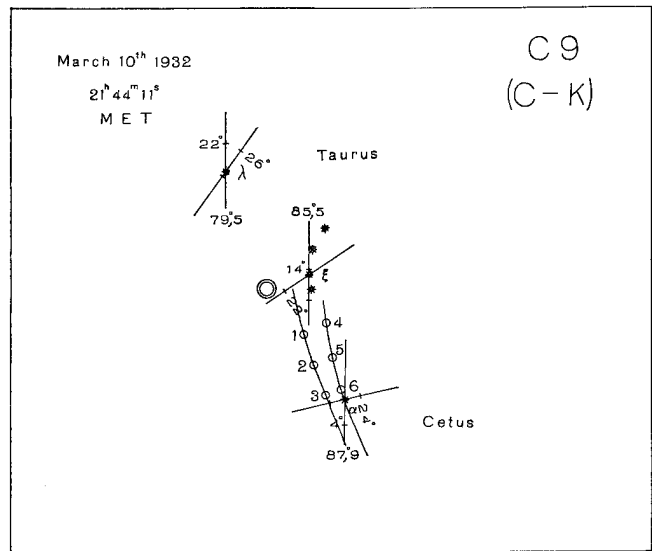
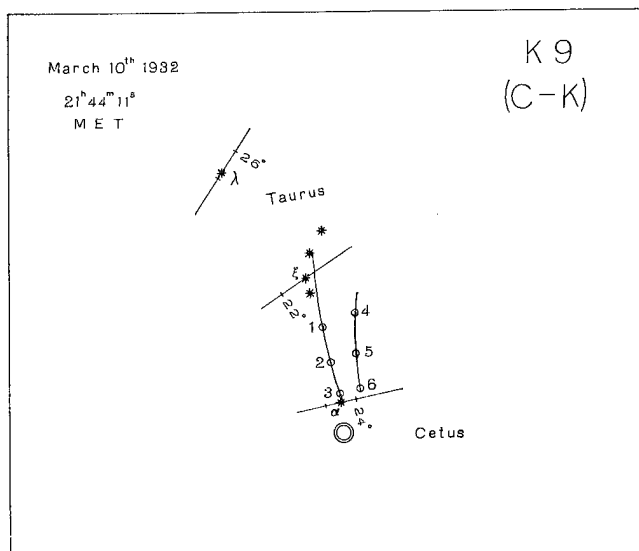
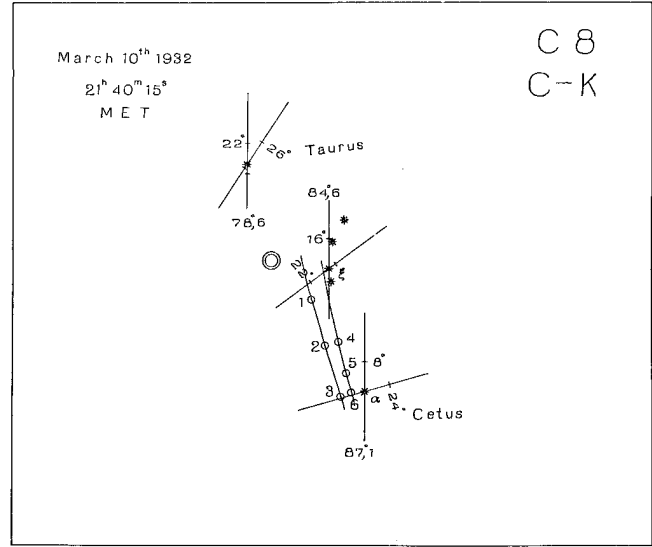
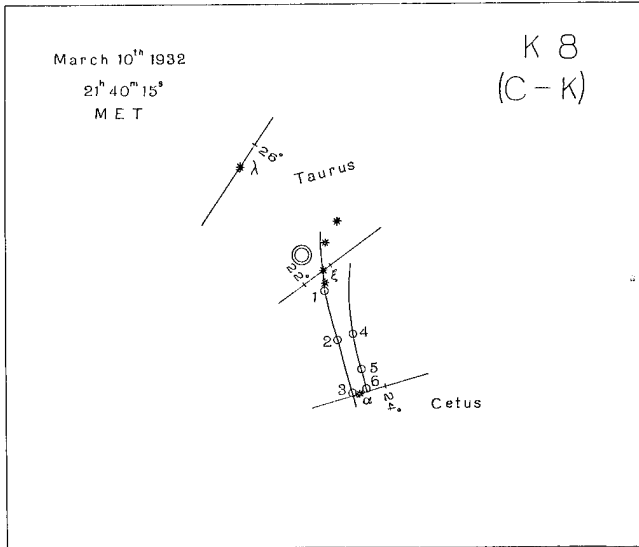
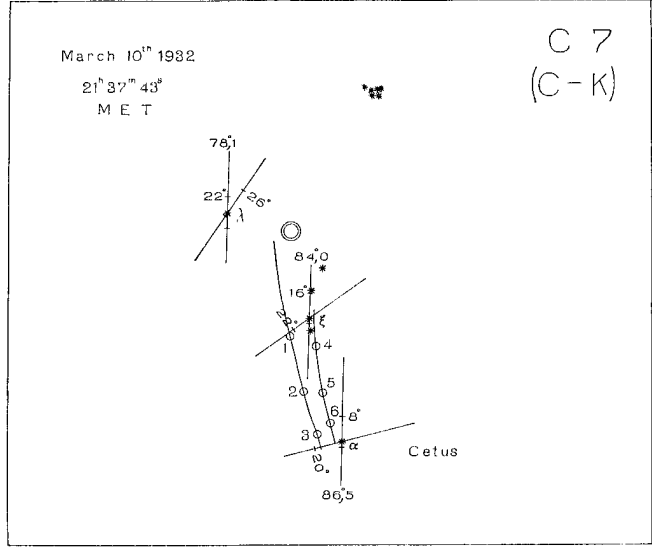
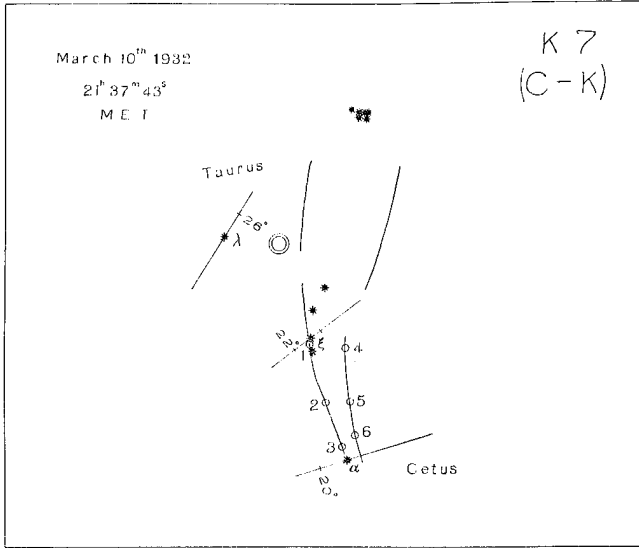


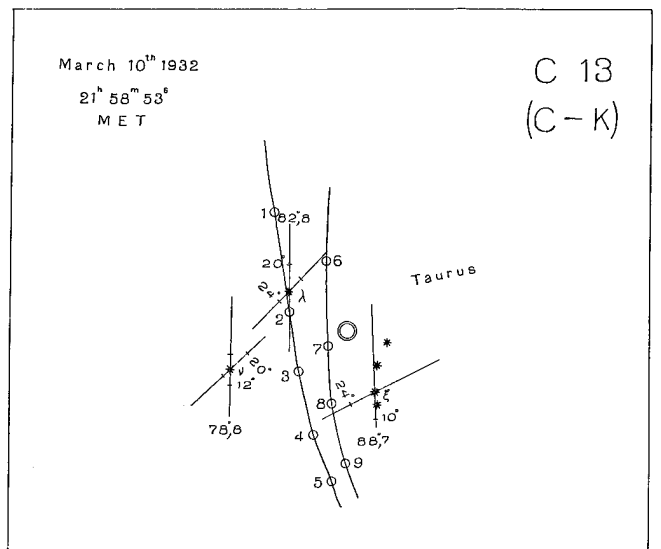
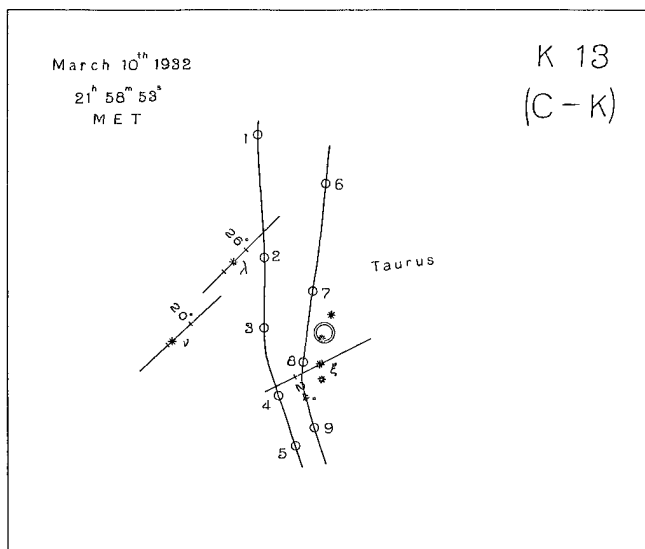
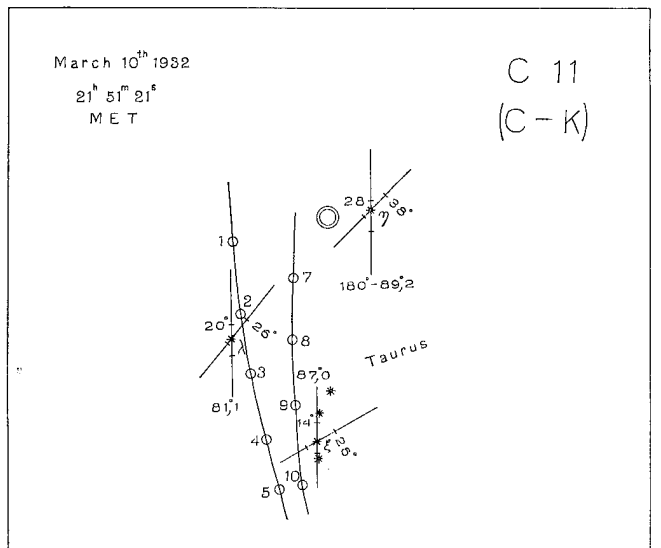
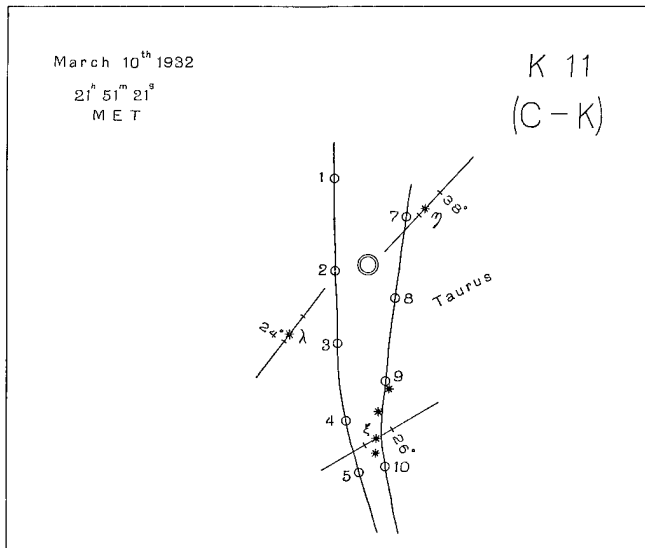
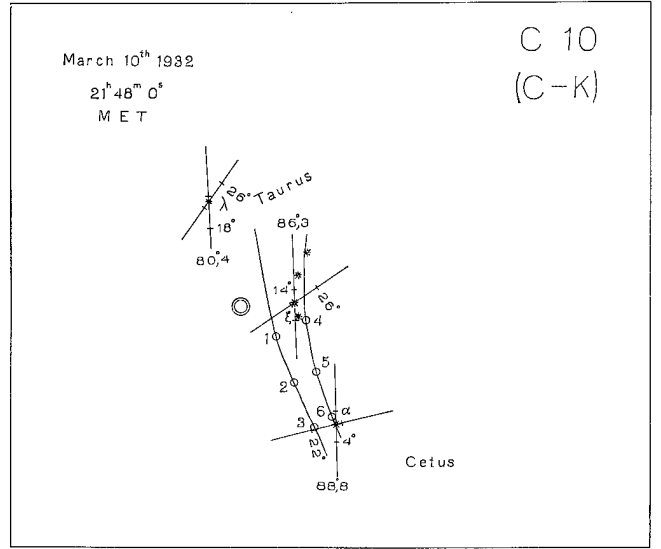
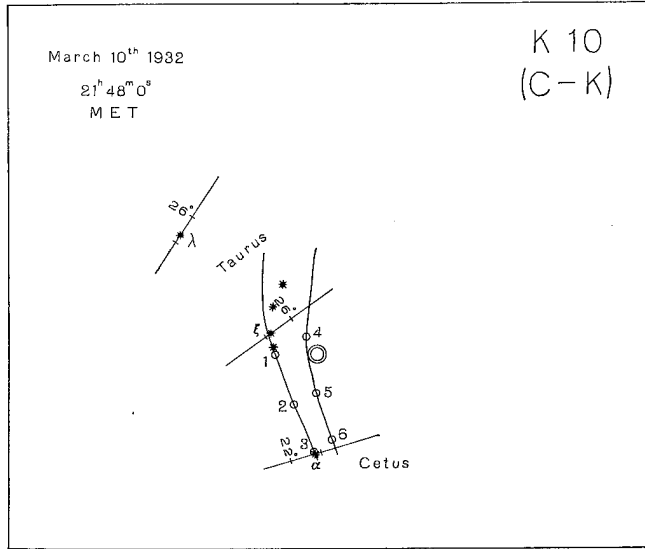


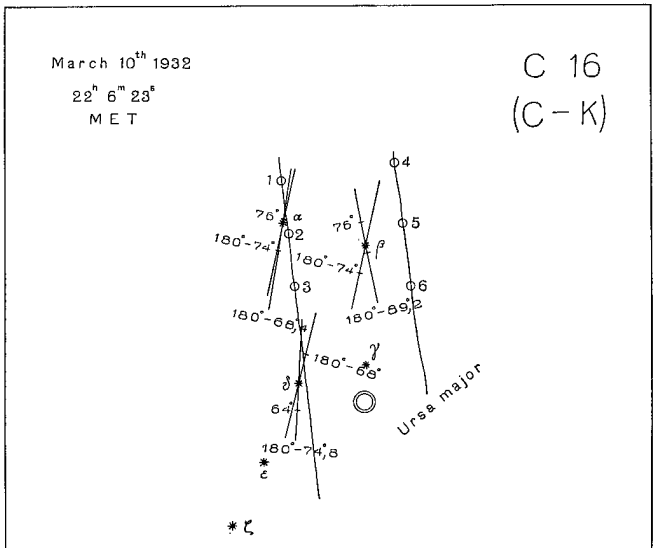
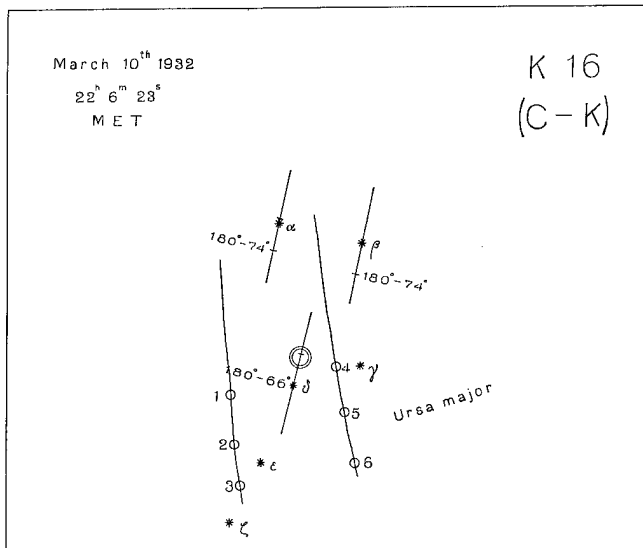
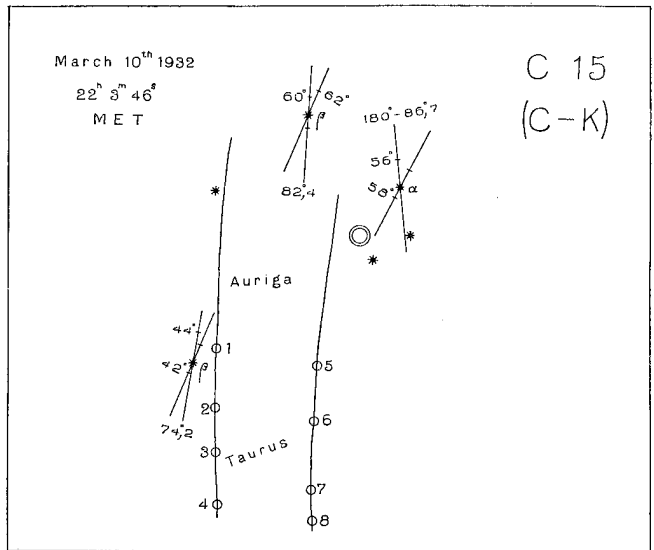
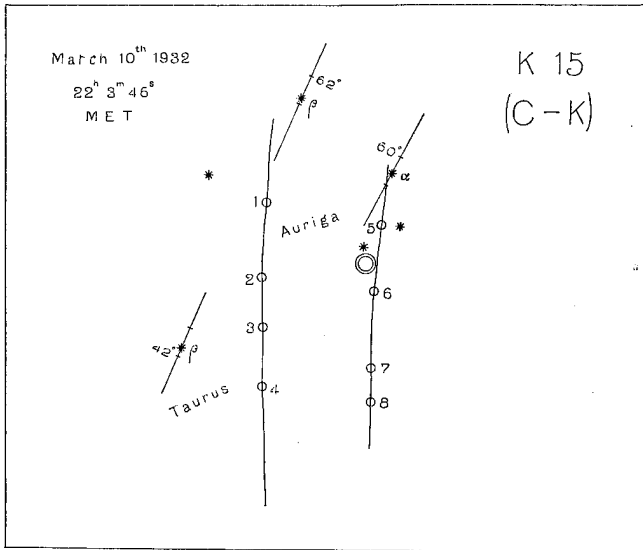
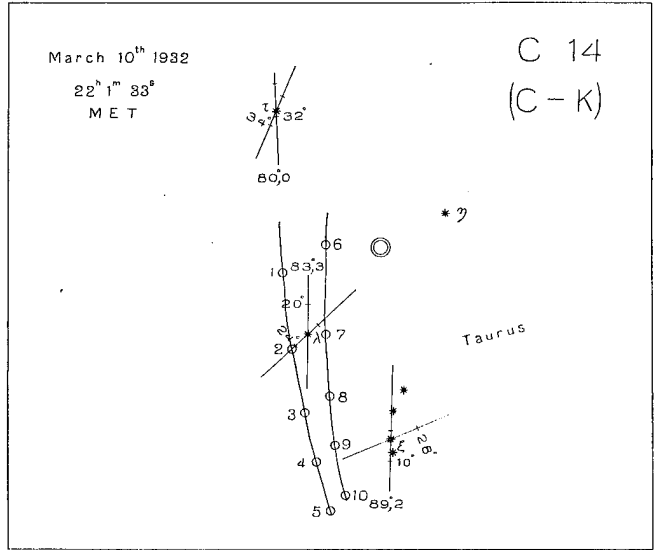
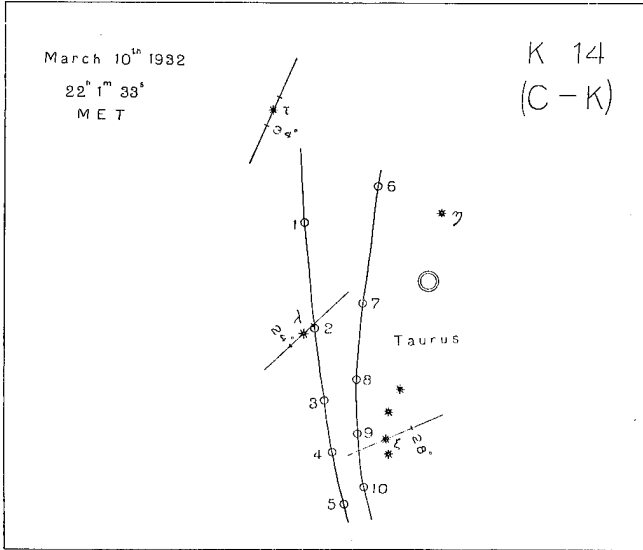


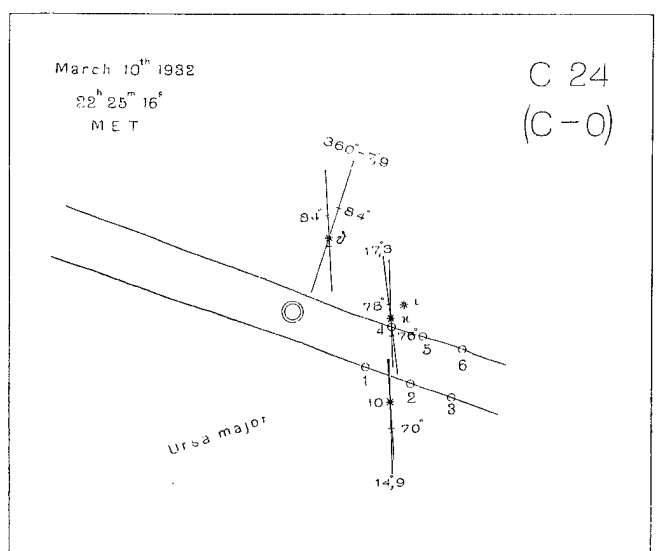
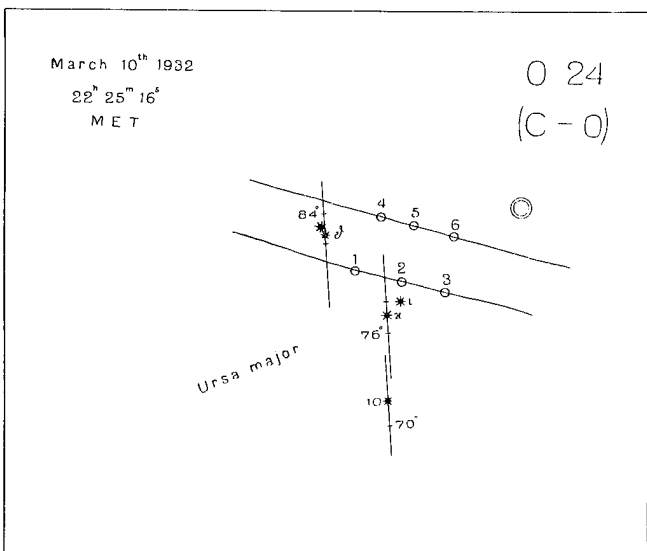
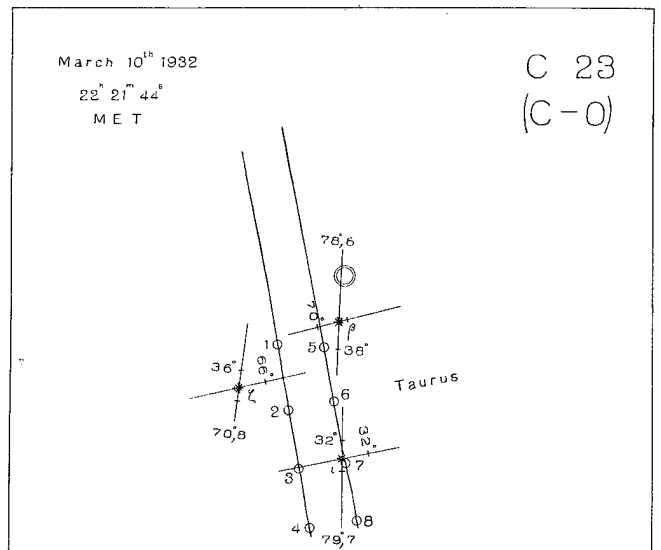
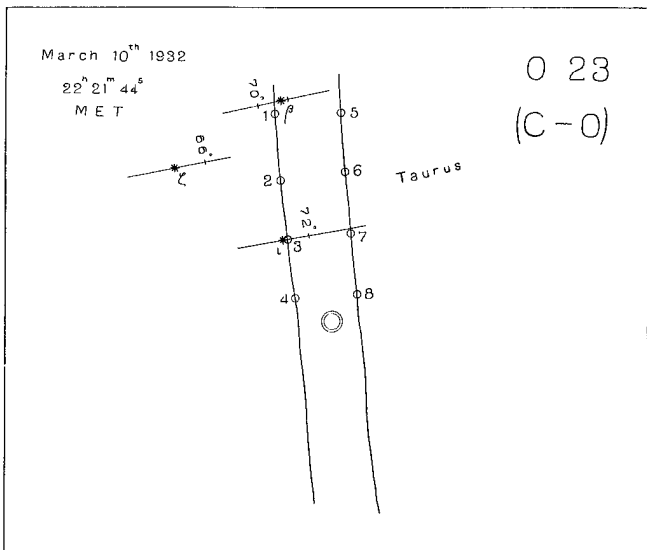
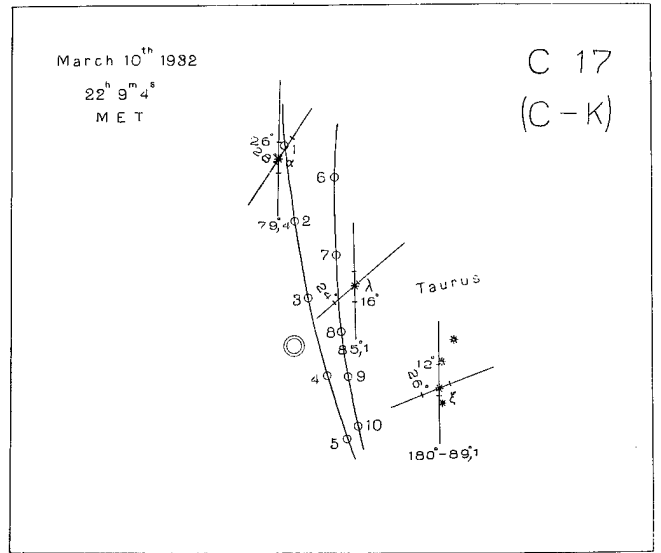
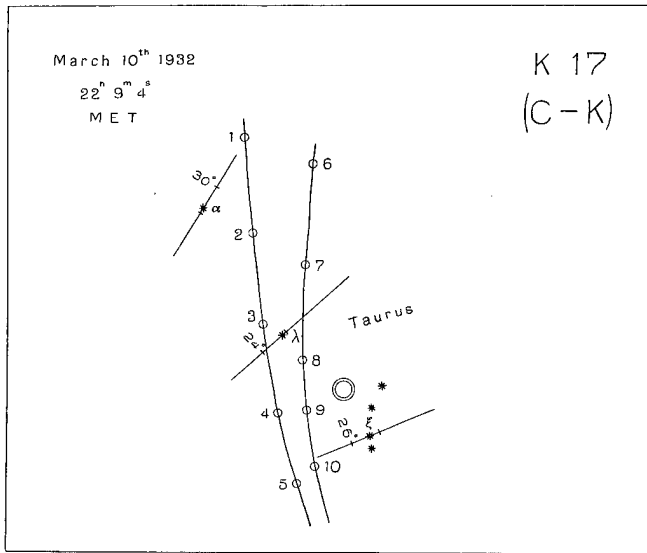


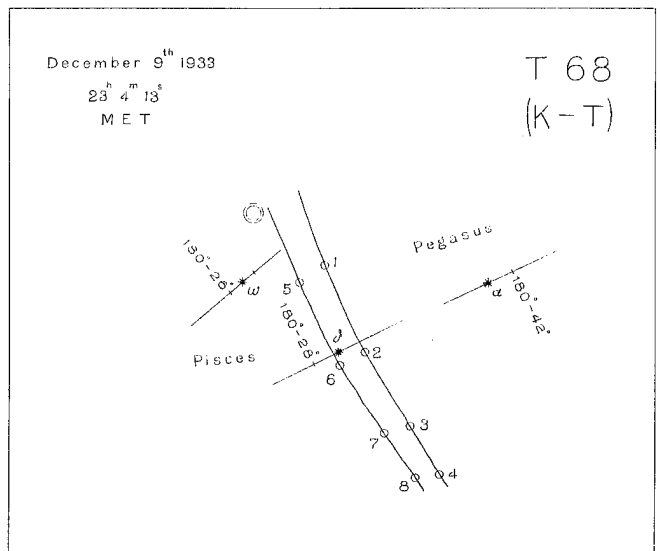
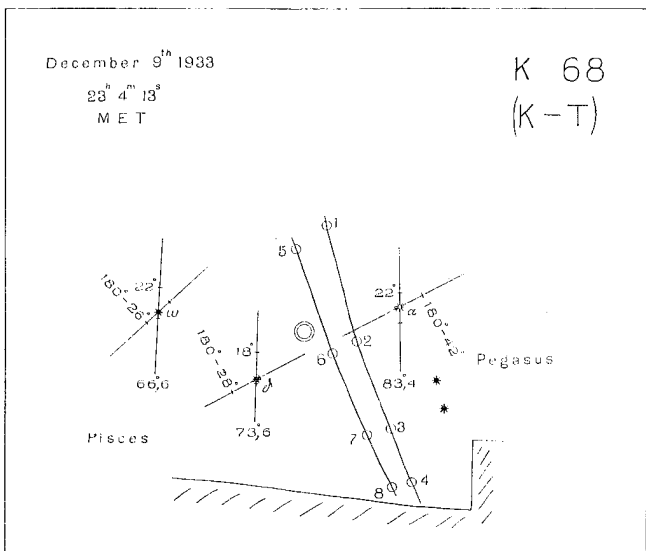
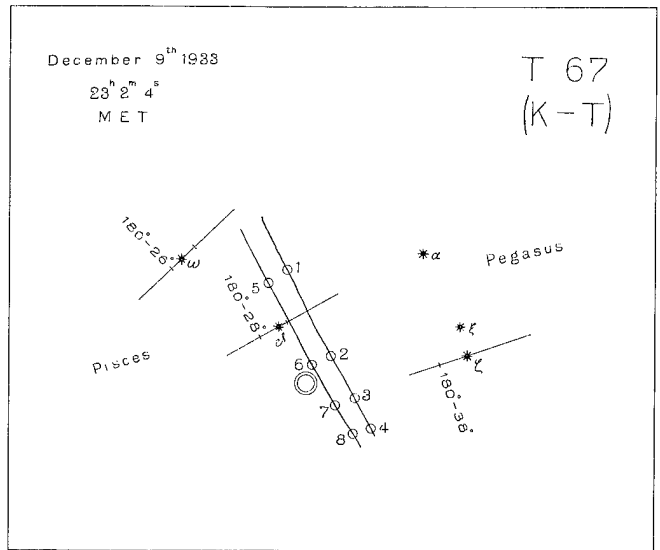
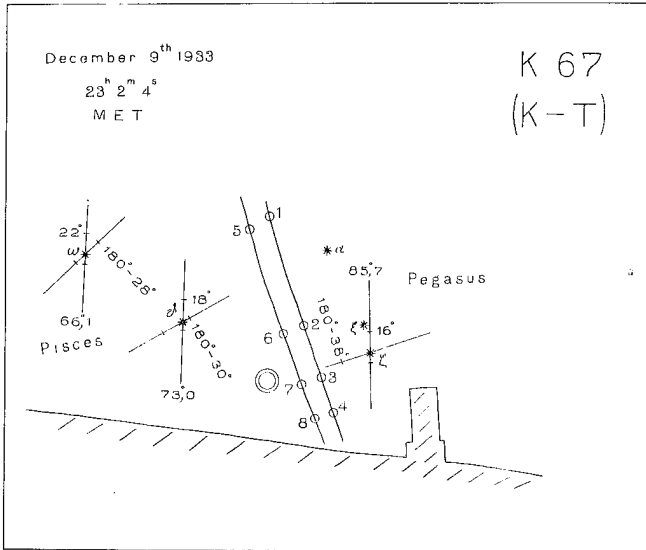
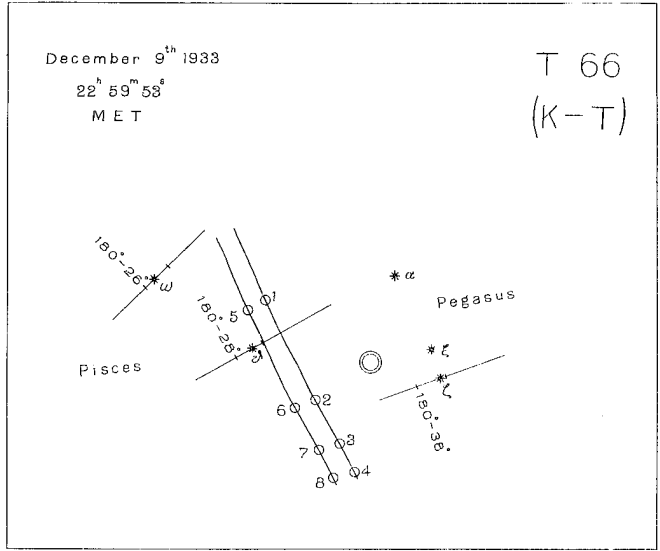
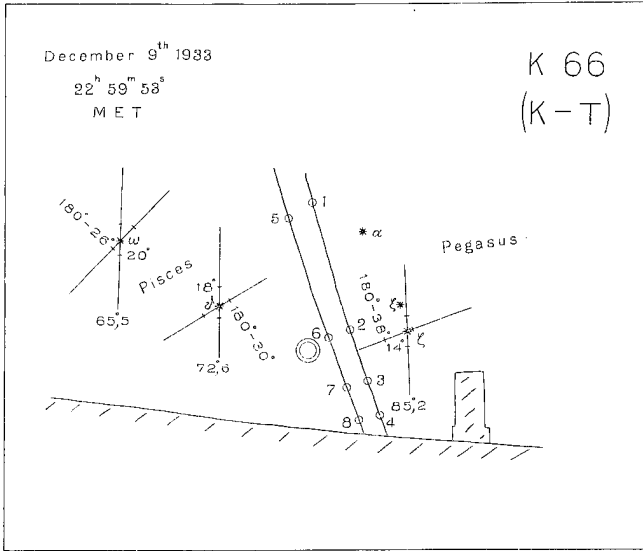


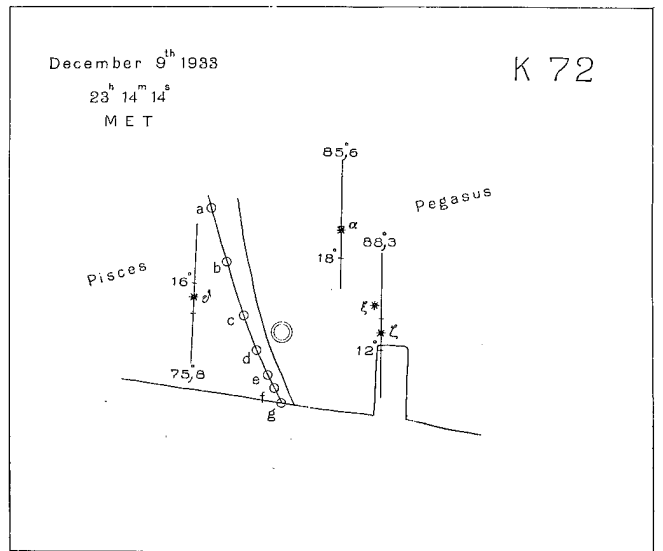
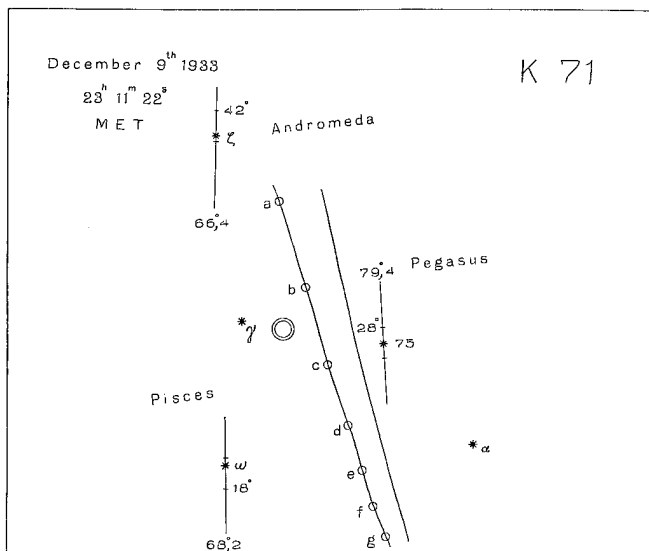
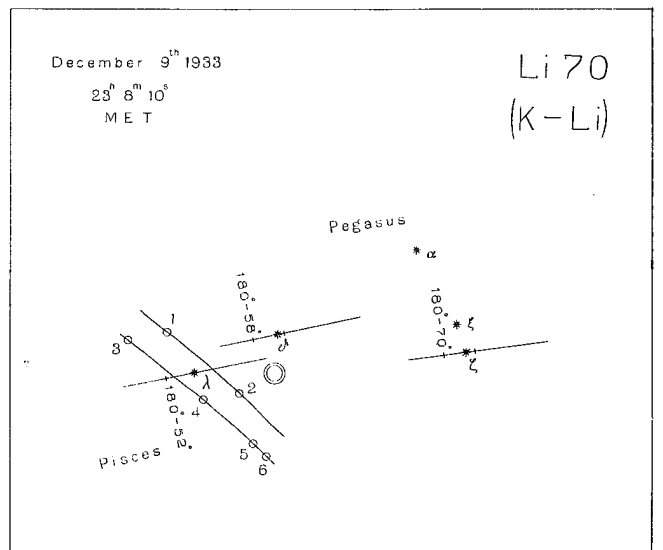
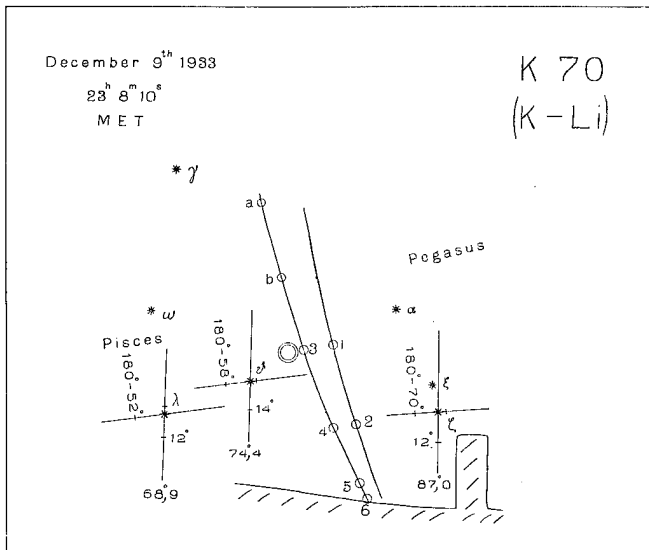
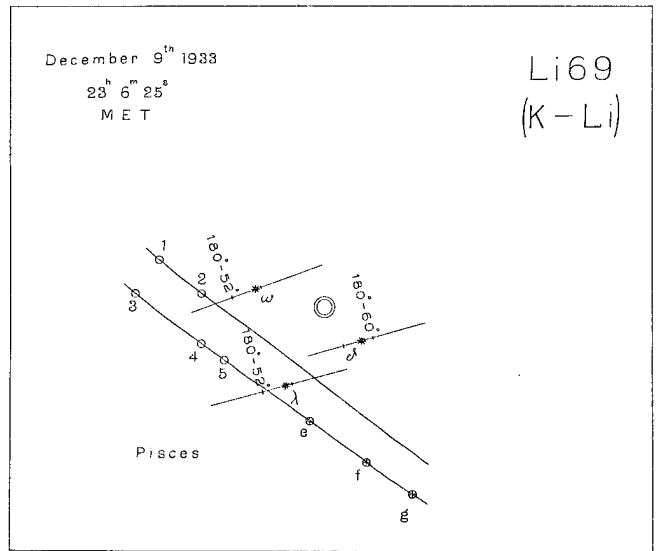
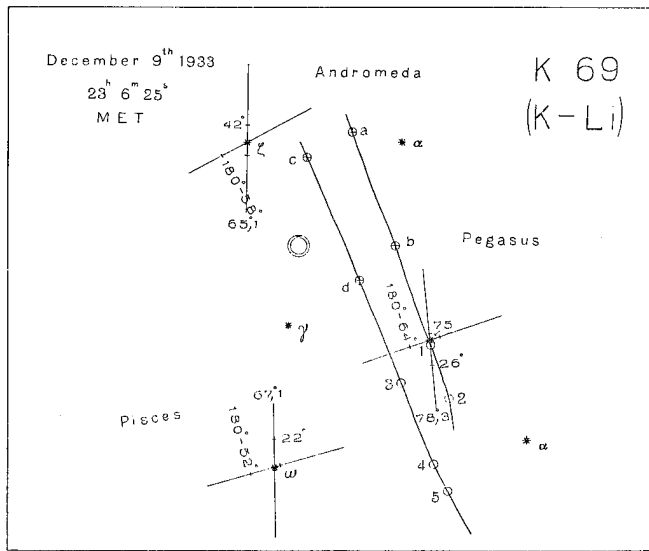


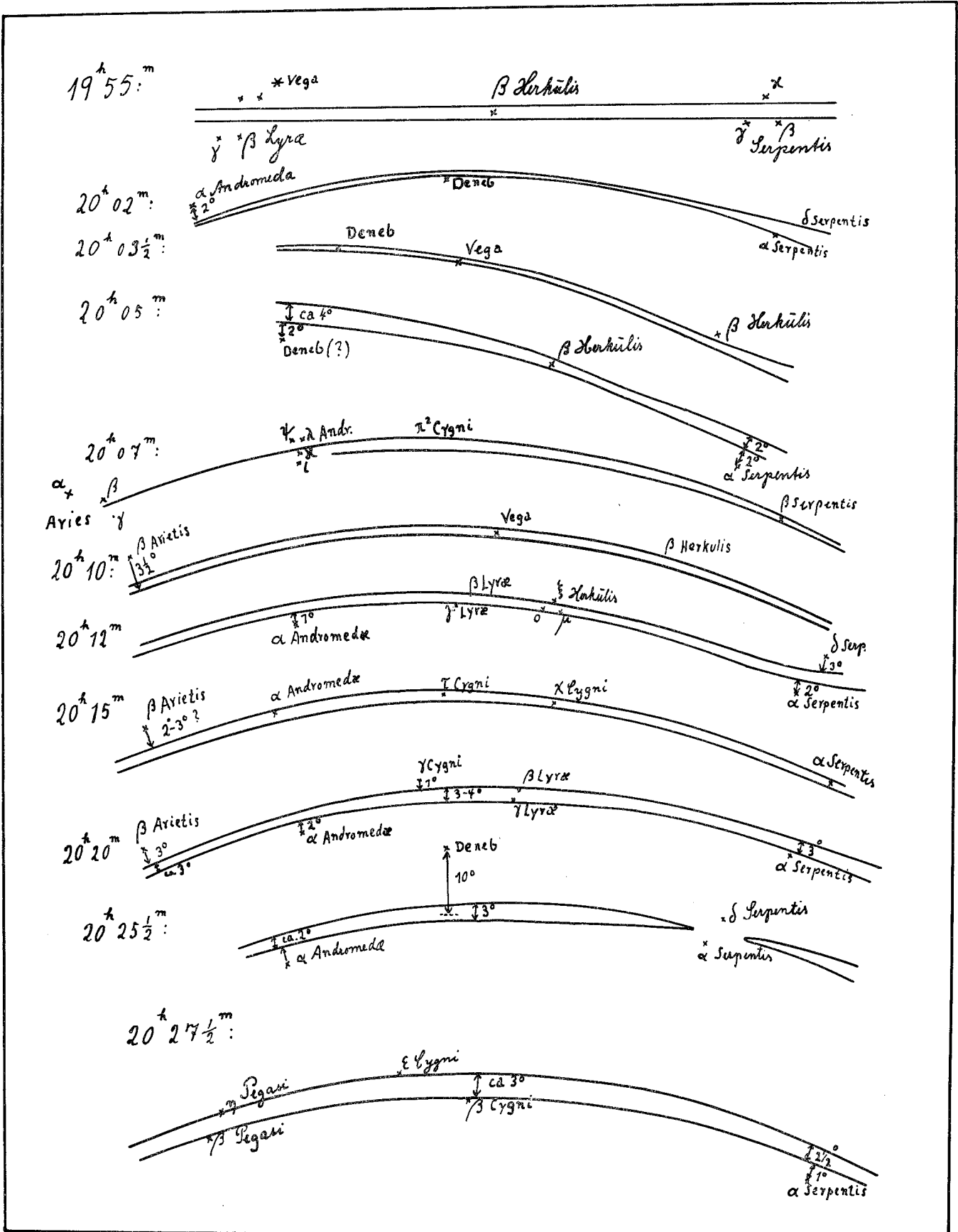


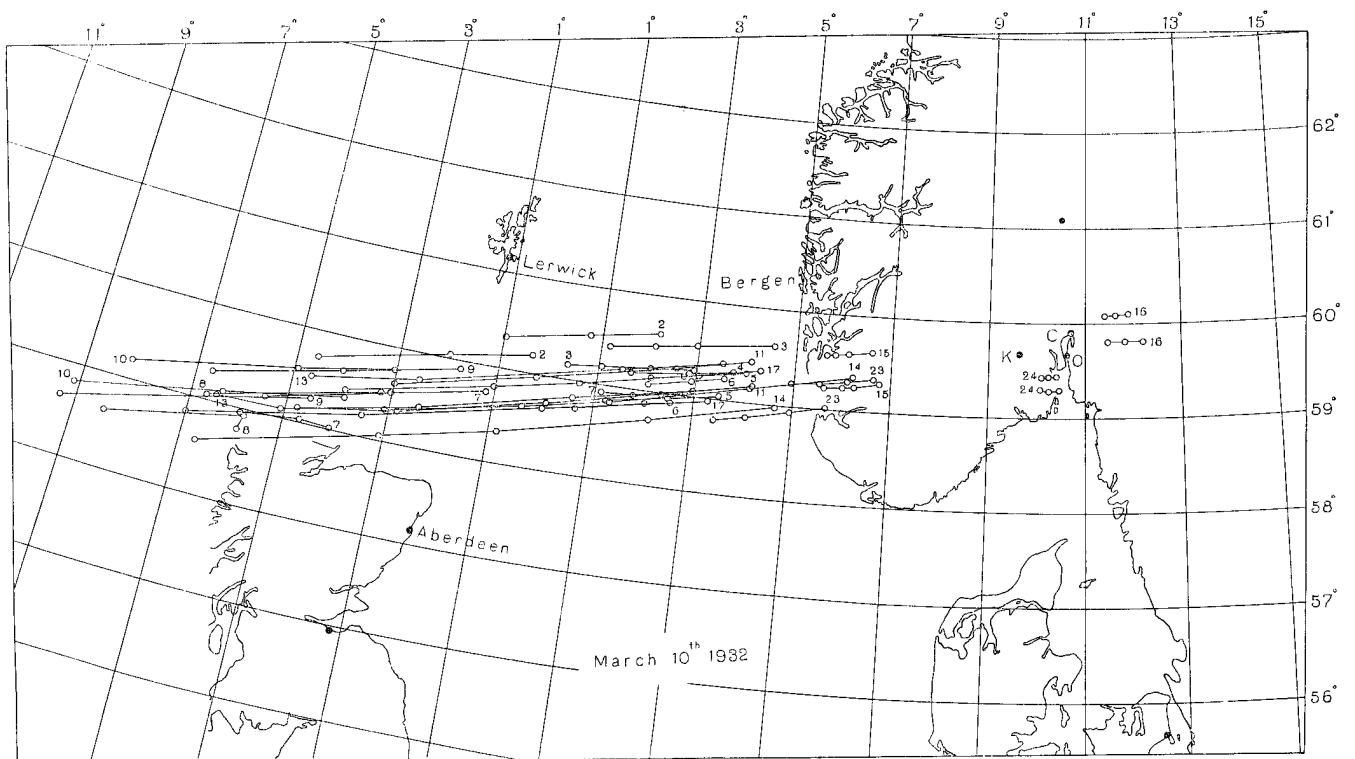
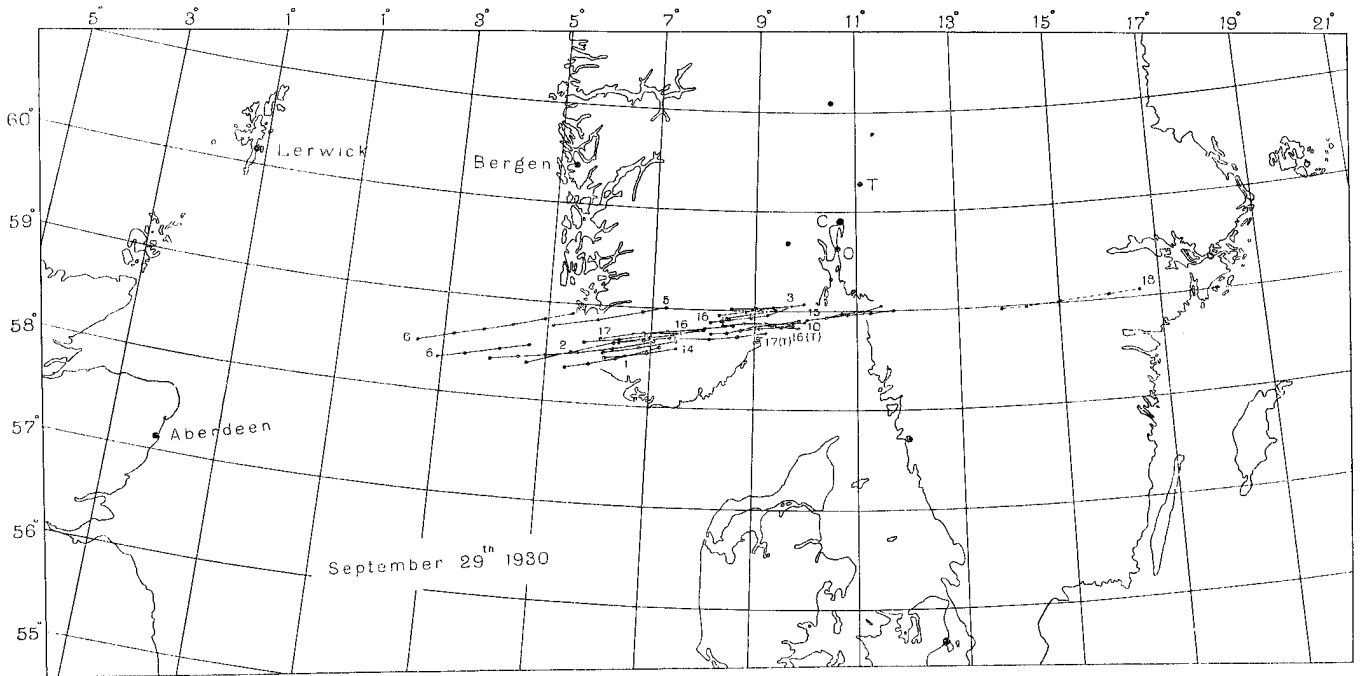


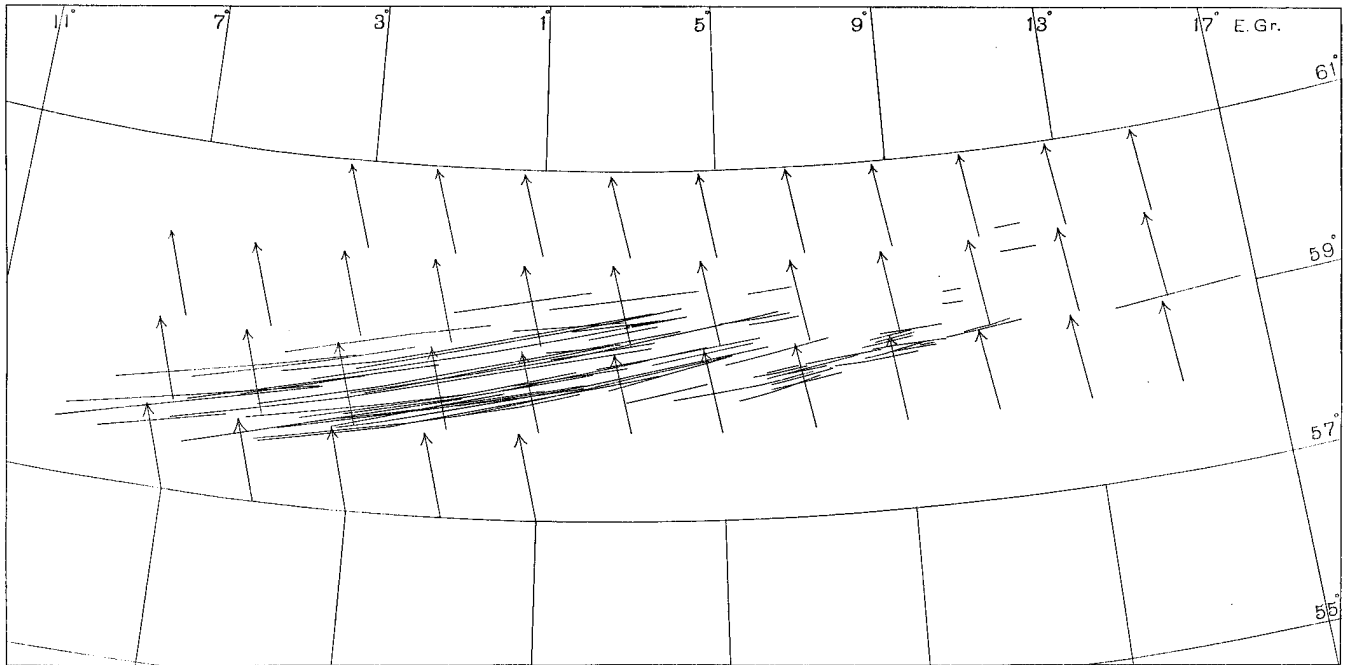
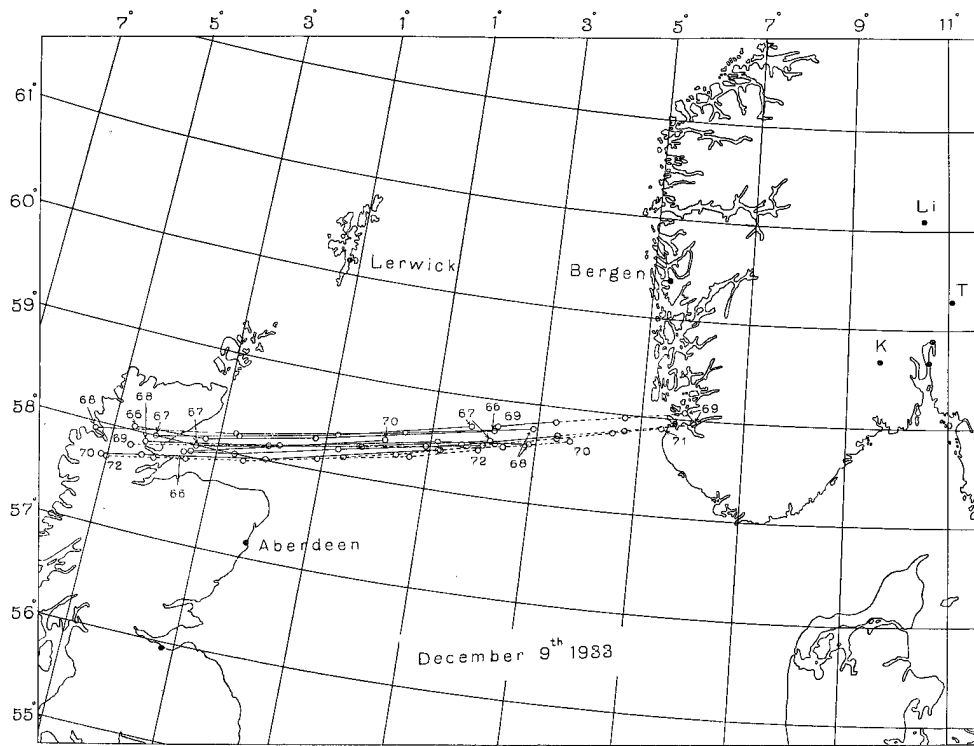










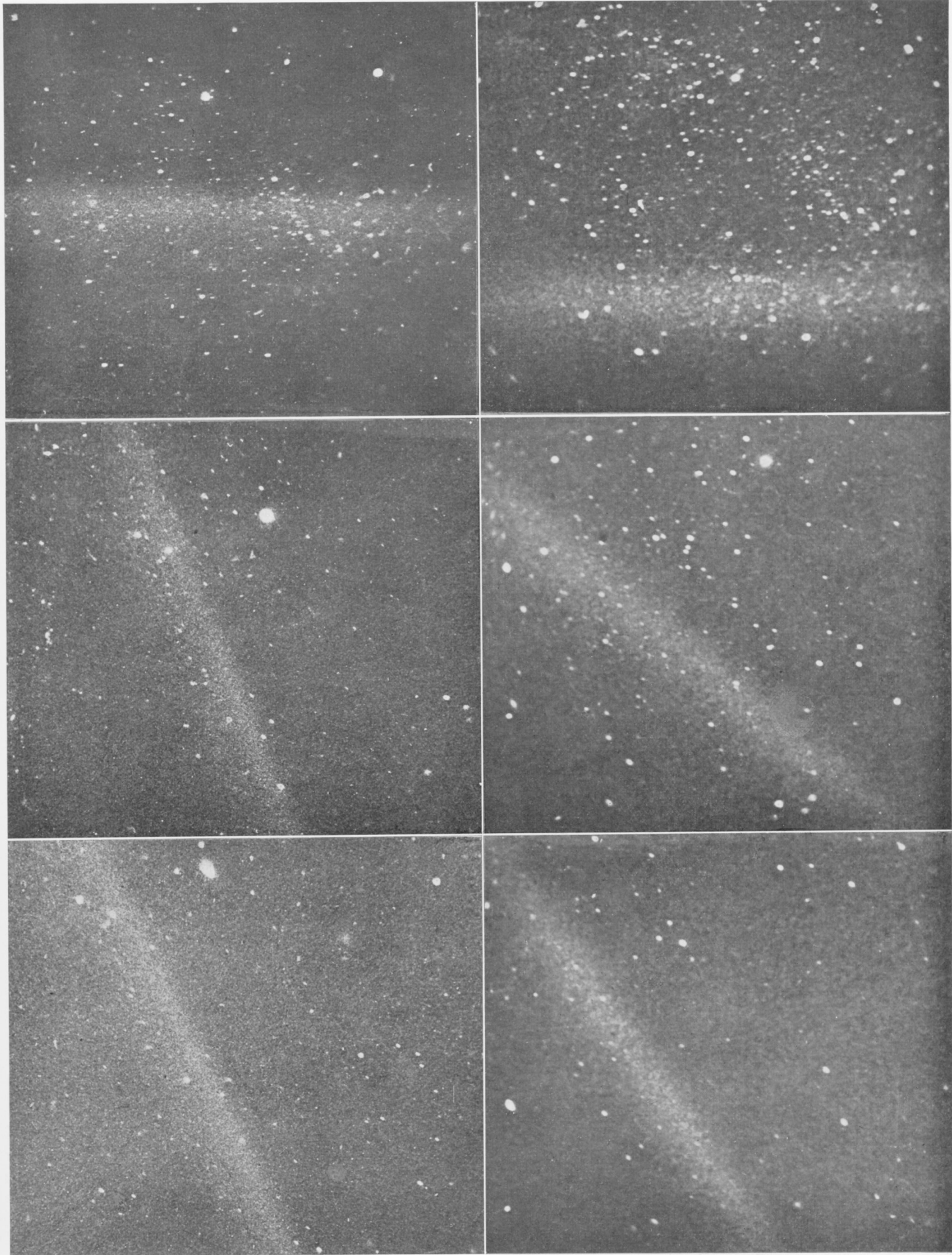


Explanation to Plate XVI.

All the pictures on this plate were made in the following manner:
From the original negatives new diapositives were made on a slow lantern-slide plate and from these new negatives and therefrom enlarged copies on bromide paper. By this process, called "Process P" below, the contrasts were considerably strengthened.

1. 29 September 1930, O 15.
2. C 15, taken simultaneously.
3. Same date O 16.
4. C 16, taken simultaneously.
5. Same date O 17.
6. C 17, taken simultaneously.

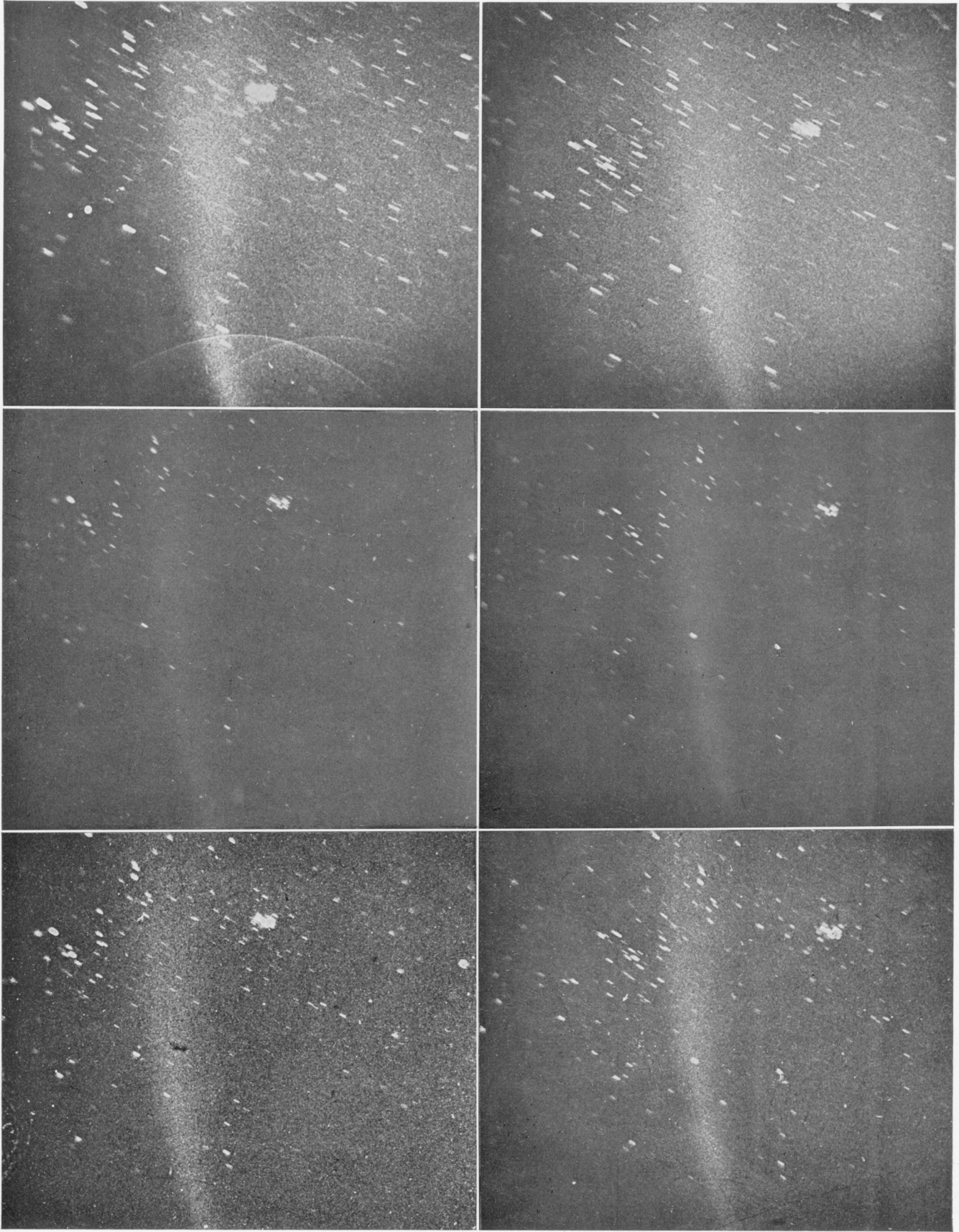
1	2
3	4
5	6



Explanation to Plate XVII.

1. 10 March 1932, Picture K 11, by Process P.
2. Same date, corresponding picture C 11, by Process P.
3. 10 March 1932, Picture K 14. Enlarged from the negative direct.
4. Same date, Picture C 14. Enlarged from the negative direct.
5. Same as No. 3, by Process P, to show how the contrasts are increased.
6. Same as No. 4, by Process P.

1	2
3	4
5	6



Explanation to Plate XVIII.

1. 10 March 1932, K 13, enlarged from the negative direct.
2. Same date, C 13, enlarged from the negative direct.
3. 9 December 1933, K 67, enlarged from the negative direct.
4. Same date T 67, by Process P.
5. Same date K 68, enlarged from the negative direct.
6. Same date T 68, by Process P.

1	2
3	4
5	6

