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DETERMINATION OF DRIFT MOVEMENTS OF THE IONOSPHERE AT HIGH LATITUDES FROM RADIO STAR SCINTILLATIONS

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Summary. Scintillations in the radio noise emission from the Cassiopeia source on 45 mc/s have been recorded at three stations lying in the corners of a right-angled triangle with bases equal to 600 m. The observations were made at Tromsø ($\varphi = 70°$N) close to the auroral zone. The time delays, T_x and T_y, representing drifts components in the E-W and N-S directions were recorded around upper and lower culminations of the radio source for a period covering about half a year. It is shown that the sidereal variation of T_x and T_y is determined by the hour of upper and lower culmination of the radio source, which at Tromsø also coincides with the time of passage across the geomagnetic meridian. The time delays T_y corresponding to the N-S drift component are considerably greater than the T_x-values, and the direction of the N-S component reverses when the radio source crosses the N-S (or geomagnetic) meridian. The T_x-values corresponding to the E-W drift component have median values which always indicate a drift towards W of a magnetude of 400—600 m/s.

It is shown that the characteristic reversal of the N-S component is explained if a uniform drift towards W is assumed, and that the diffraction pattern on the ground consists of strongly elongated ellipses with their major axis directed along the projections of the geomagnetic field lines seen from the radio source. The hypothesis put forward by SPENCER that the scintillations are due to elongated blobs aligned along the geomagnetic field is thus supported.

CONTENTS

1. Introduction. When radio wave emission from a radio star passes through the ionized regions of the upper atmosphere the refractive index of the ionized air may, at certain time intervals and over certain areas, attain values which are different from, and usually less than unity for the wave lengths considered. The ionosphere will thus act as a diffracting screen and irregularities in the electron concentration of the ionosphere will produce a diffraction pattern on the ground. These scintillation effects are especially pronounced at meter wave-length, in the region 30—100 mc/s. The scintillations appearing in the amplitudes recorded of radio wave emissions from radio stars have been studied during recent years with the views: *a*) to study the *structure* of the irregularities in the ionosphere constituting the diffraction screen, and *b*) to study the *drift* of the diffraction pattern on the ground and the structure of this pattern.

It has not been possible from analysis of the scintillations directly to determine the height of the diffraction screen, but observations from Cambridge and Jodrell Bank show a correlation between the appearance of spread *F* and the amplitude of the scintillations. It is therefore assumed that the diffraction screen is lying in a height of about 400 km. A direct measurement of the height of the screen has been possible using a satellite as a source of radio wave emission, and it has been shown that both at Kjeller (60° N) and Tromsø (70°) the height of the diffracting screen is 300—500 km [1].

The diffracting screen is usually considered to be a phase-modulating screen where the various amplitude components add up on the ground with different phases. Assuming phase deviations to be less than a radian the structure of the diffraction pattern on the ground will be of the same order as in the diffracting screen [2, 3] and from correlations studies of the diffraction pattern on the ground it will be possible to determine the average size of the blobs in the diffracting screen.

Simultaneous observations of scintillations at two places about 1 km apart revealed a time lag between the amplitude maxima on the records from the two stations. Interpreting these time delays as a result of a drift of a diffraction pattern on the ground it should be possible to apply the method of simular fades (Mitra method) for a closer study of the drift effects.

Observations at Cambridge [5] and at Jodrell Bank [3] using three recording stations placed in a triangle showed clearly drift effects, and the most remarkable feature was strong E-W component with a predominence towards W. According to Maxwell and Dagg [5] there was a diurnal variation in the drift direction, being towards W before midnight and mainly towards E after midnight.

In these first drift studies the diffraction pattern was assumed to be isometric, and the diffracting screen in the ionosphere was assumed to be lying in a height of about 400 km. From drift studies of the *E*-layer it is known, however, that the diffraction pattern due to *Es*-reflections may be anisometric. For the diffraction screen producing the scintillations it is expected that the anisometry effects will be still more predominant. Due to the great differences in the values of the diffusion coefficient of the electrons along and perpendicular to the geomagnetic field at these great heights a circular blob of ionization will diffuse mainly along the geomagnetic field lines and in short time appear as a field aligned irregularity in the general background of ionization. SPENCER [6] showed convincingly that these field aligned irregularities will produce a strong anisometry in the diffraction pattern. From observations at Cambridge the characteristic ellipse of correlation was determined and Spencer showed that the major axis of this coincided with the projection on the ground of the geomagnetic field lines as seen from the radio star. Movements of the diffraction pattern on the ground in any direction will on the records at the three receiving points appear mainly as drifts in the direction of the minor axis of the characteristic ellipse, and the drift directions will thus change with the sidereal movement of the radio star relative to the geomagnetic meridian. JONES [4] has extended this study and from a full correlation analysis determined the true drift directions in a number of cases (29). It is remarkable that in 23 cases the drift direction is lying in the NWS-segment and in 6 cases only in the NES-segment.

Due to the drift of the diffraction pattern the fading rate will depend on the velocity of drift and the dimensions of the blobs. The fading rate is usually of the order 10—15 sec/fading and the drift speed may be of the order 300 m/s. This gives a blob size of the order of 3—4 km. HEWISH [3] showed that the drift speed depended on the geomagnetic activity, with increasing K-figures the drift speed increased.

2. **Experimental arrangement.** The three observing points were situated at the corners of a right-angled triangle, the base-lines N-S and E-W were both 600 m. The recording equipments were three phase-switching interferometers. The frequency used was 45 mc/s, and the radio star used was the Cassiopeia source. The base-line of each interferometer was 9λ and the aerials were two three elements Yagis which could be directed either towards the upper or lower culmination heights of the source. From each of the three receivers a low impedance output was fed through cables to a common recording room in the observatory. The normal recording paper speed for drift measurements was 1"/10 sec and the mean relative time displacement from a series of maxima could usually be estimated down to 0,2 sec. The amplifiers at the three receiving points were identical and care was taken in order to attain the same time constants of the three recording equipments. Three values of time constants were available, $t_c = 1, 1.5, 3$ sec, and usually a time constant of 3 sec was used. It was evident however, that when using this time constant there was a considerable averaging of the very rapid fluctuations which often occurred especially during strong geomagnetic activity.

There was a high degree of correlation between the amplitude variations at the three recording points and no attempt was made to study the degree of correlation between the receiving points, for this purpose the baselines ought to be greater.

3. **Observations.** The observations were made at the Auroral Observatory, $\varphi = 69.7°$ N, $\lambda = 18.6°$ E Gr., Tromsø, which is situated about 300 km to the south of the "normal" auroral zone. The recordings showed that it was not possible to obtain a smooth sinusoidal curve during the upper or lower culmination of the Cassiopeia source even at geomagnetically most quiet conditions. Fig. 1*a* shows a record taken

during geomagnetically very quiet conditions, Fig. 1*b* is from a day with slight geomagnetic disturbance. Fig. 1*a* shows some few but deep fadings (about 0,5 fadings/min). On Fig. 1*b* the fading rate has increased strongly (up to about 3 fadings/min) and this latter record is typical for Tromsø.

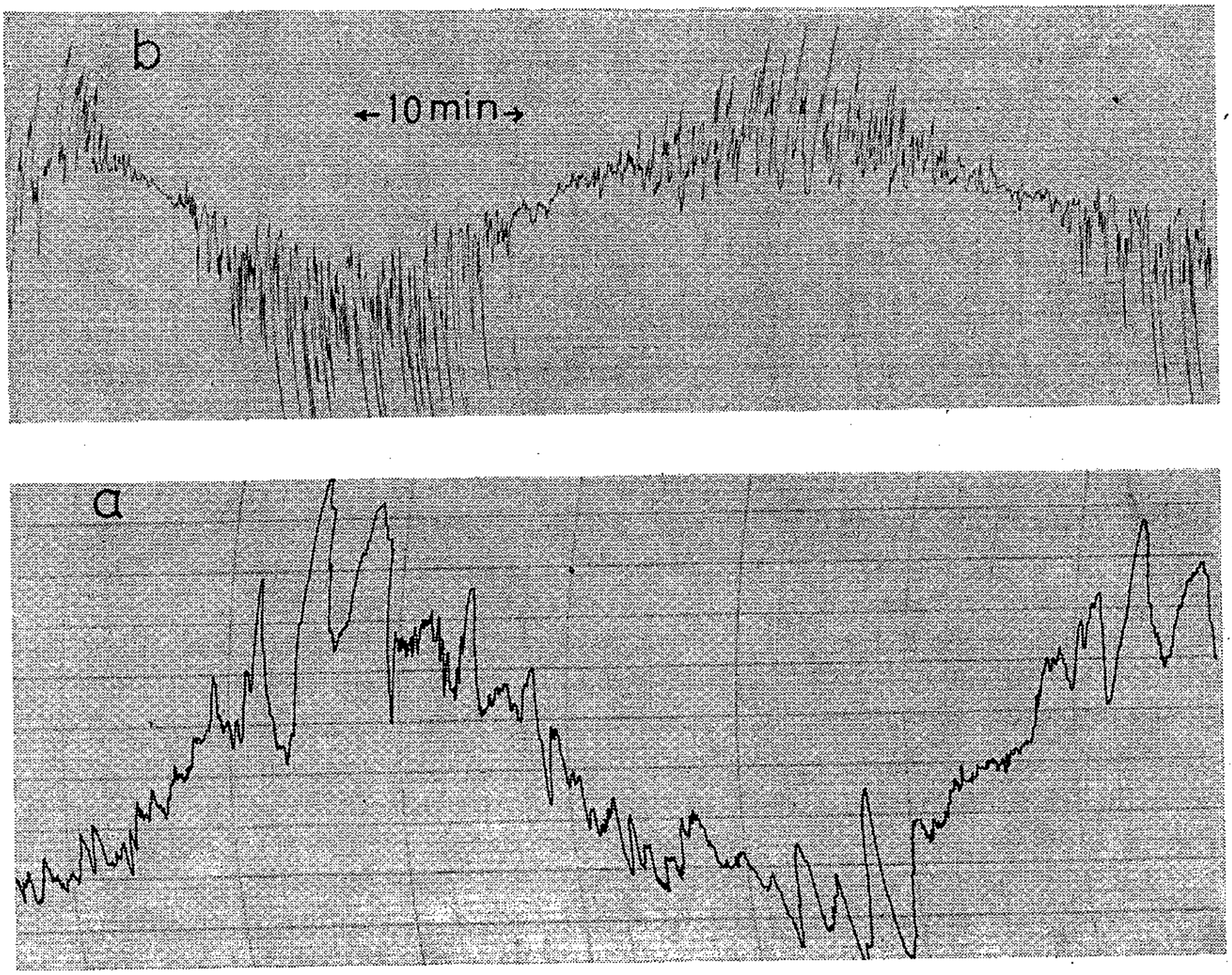

Fig. 1*a*. Scintillations during geomagnetically very quiet conditions. *b*. Scintillations during small geomagnetic disturbance.

On Fig. 2 are shown the simultaneous records from three points, recorded on an extended time scale. There is a strong correlation between the amplitude variations at the three points. The time delays between *C* and *S* (*N-S* direction) are considerable (about 2 seconds) whereas there is a small delay (about 0,4 seconds) between *C* and *E* (*E-W* direction). The time delays T_x and T_y along the E-W and N-S bases were arranged as function of the time of passage of the Cassiopeia source before and after upper and lower culmination. On Fig. 3 left the observations at upper culmination and on Fig. 3 right the same for lower culmination have been given for the period Feb.—May and Nov.—Dec. 1958.

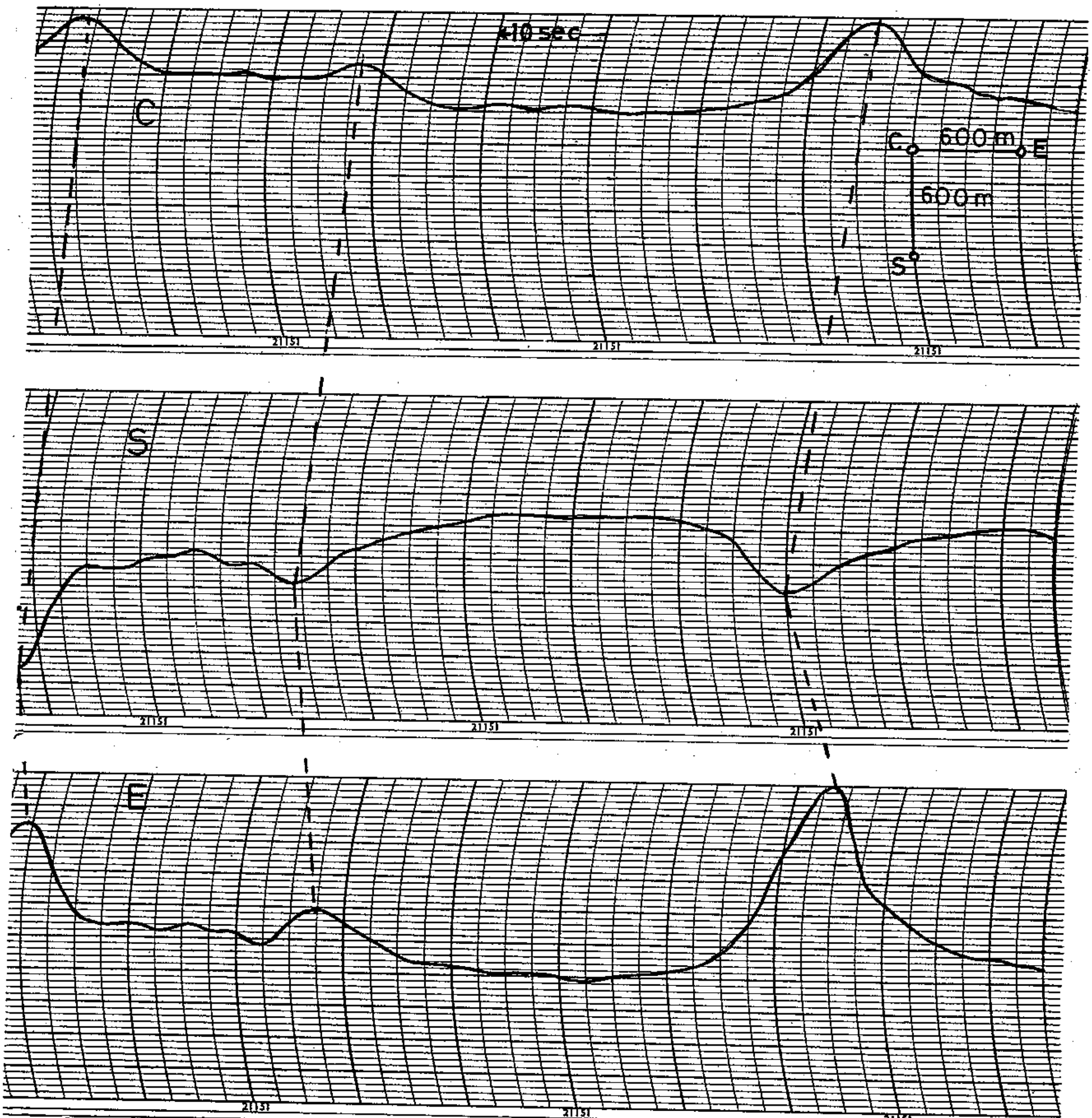

Fig. 2. Records from three points showing time delays over the N-S and E-W bases.

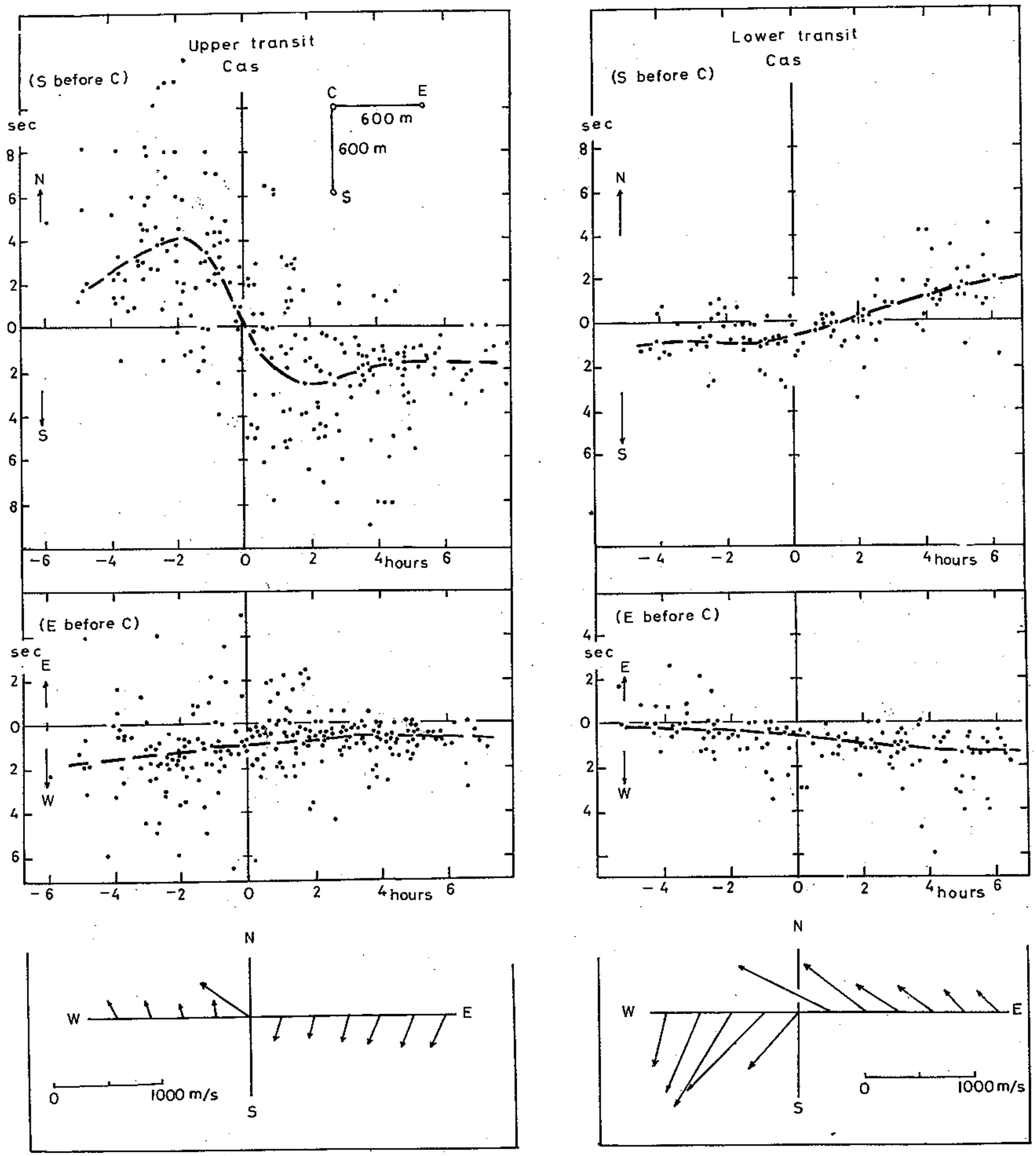

Fig. 3. The median curves for *Ty* and *Tx* at upper and lower culminations. The material for 1958 has been used. In the lower part of the figure the wind vectors around upper and lower culminations are given assuming isometric diffraction pattern.

On Fig. 3 are the median curves given showing the variation of T_y and T_x around upper and lower culminations, and using the whole material for 1958. It is evident that there is a characteristic variation with time which seems to be dependant only on the time of upper and lower culmination of the Cassiopeia source, and independant of time of the day and season of the year.

If the diffraction pattern is assumed to be isometric it will be possible from the median values of T_y and T_x to evaluate the true mean drift of the diffraction pattern. The wind vectors given in Fig. 3 are based on this assumption.

Wind vector diagrams based on the assumption of isometric diffraction pattern has been given by MAXWELL and DAGG [5] using recordings from Jodrell Bank. There is a considerable difference between the diagrams from Jodrell Bank and Tromsø. At Jodrell Bank only small time shifts occur along the N-S base, the main drift effects are confined to the E-W directions, whereas at Tromsø the greatest drift effects occur along the N-S base. The wind vector diagrams at these two places will therefore be entirely different, at Jodrell Bank the wind vectors will lie in E-W direction whereas at Tromsø the main direction will be along N-S. HEWISH using records from Cambridge also had the greatest time delays along the E-W base.

It is obvious that the variation in the drift direction, indicated in Fig. 3 which indicates a reversal from upper to lower transit can not be physically real, and that the assumption of a drifting diffraction pattern which is isometric is not correct. It will be shown in the following that the difference in the variation of the time delays T_y and T_x from England to Tromsø is due to the geometry of the radio wave transmission relative to the direction of the geomagnetic field at these two places of observations.

4. The Projection of the Geomagnetic Field Lines.

In the following it will be shown that the variation of the median values of T_y and T_x around upper and lower transit at Tromsø can be explained if we assume:

i) a mean drift *towards W* of a magnetude of 400—600 m/sec, and

ii) an anisometric diffraction pattern consisting of elongated blobs, where the main direction lies along the projection of the geomagnetic field lines as seen from the Cassiopeia source.

The coordinates for Tromsø are $\varphi = 69.7°$ N, $\lambda = 18.6°$ E Gr. The inclination is $I = 77.6°$ and the declination is $D = 0.5°$ E. The declination of the Cassiopeia source is $\delta = 58.5°$. At Tromsø one thus have the following simple geometry of movement of the Cassiopeia source relative to the geomagnetic field lines:

a) the geomagnetic N-S direction coincides with geographic N-S direction (to less than 1°),

b) at the time of *upper* transit the height of the Cassiopeia source is 78.8°, and the geomagnetic inclination is 77.6°. At the moment of upper transit the propagation is longitudinal within an accuracy of about 1°.

A field line is selected which passes through the place of observation. At a height h above the earth's surface a point is chosen on the field line and the projection of this point on the earth's surface as seen from the Cassiopeia source is calculated. The coordinates on the earth's surface of the projection will be:

$$x = h(\operatorname{cotg} I - \operatorname{cotg} \xi \cos A), y = -h \operatorname{cotg} \xi \sin A \tag{4.1}$$

where ξ is the height and A is the azimuth of the Cassiopeia source. The projection of the geomagnetic field line will make an angle φ with the N-S direction given by $\operatorname{tg} \varphi = x/y$.

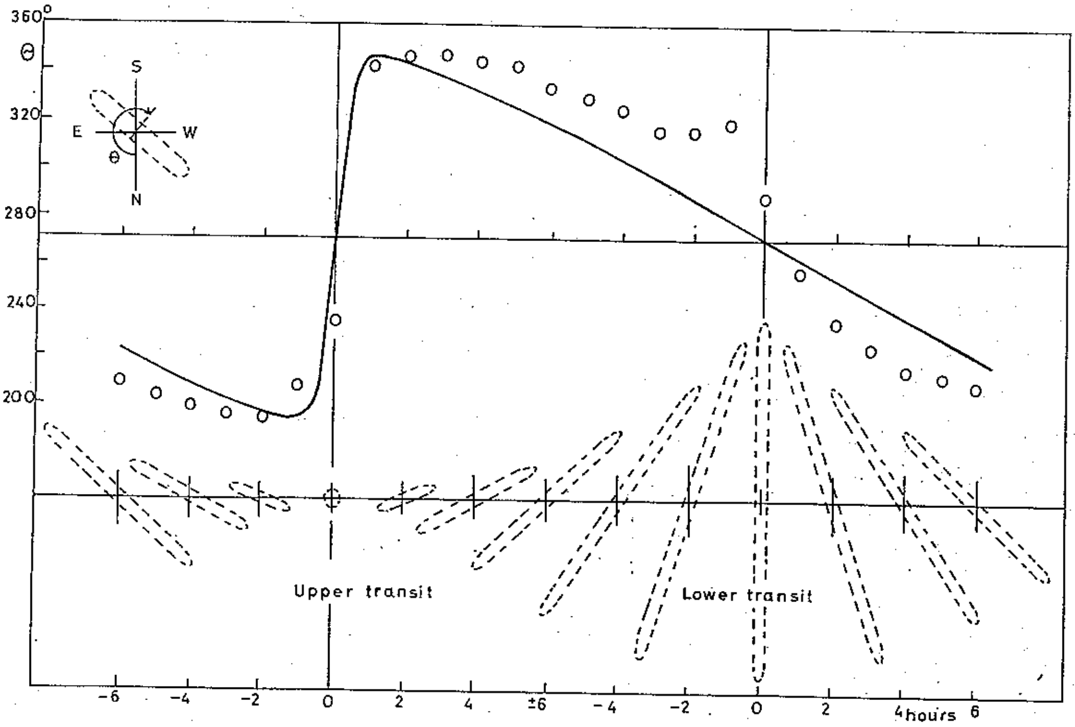

Fig. 4. Variation of the direction of projections of a field aligned blob around upper and lower culmination as seen from the Cassiopeia source. The circles indicate the apparant drift directions calculated from the median values of Ty and Tx observed, the full line the direction of the minor axis of the projections, of a blob.

On Fig. 4 is shown the variation of θ around upper and lower transit and the projections of an elongated blob with circular cross section, θ is here the angle formed by the minor axis of the projection of the blob with the geomagnetic (or N-S) meridian. If the blob was infinitely elongated drift movements in any direction would appear as a drift along the minor axis of the ellipse. The circles given in figure 4 give the drift directions calculated from the median values of T_y and T_x according to the formula $\operatorname{tg} \theta = T_x/T_y$.

There is a qualitative agreement between the change in direction of projections with sidereal time and the directions calculated from the observed time delays under the assumption of infinitely stretched blobs.

The most conspicuous feature is the rapid change in the directions of the projections with time around upper culmination. In the course of one hour the directions change more than 70°. At upper culmination we have very nearly longitudinal propagation and the projection of an elongated blob of circular cross section will be an ellipse with an axis ratio of up to $\mathrm{tg}\, I = 0.98$. A closer study of the correlation in E-W and N-S directions during upper culmination should thus give indication of if the cross section of the elongated blobs is circular.

Jones [4] has studied the size of the irregularities along the major and minor axis of the characteristic ellipse at high and low elevations of the radio source at Cambridge. He could show that there was a great difference in the "blob-size" measured along the major and minor axis. At upper and lower culmination he found a blob-size along the major axis having the same median values of about 5 km, and the size along the minor axis respectively 0,6 and 0,9 km (the horizontal extent of the ground pattern is assumed to a correlation of 0,5). Although Jones thus confirms the expected elongations of the ground pattern in the direction of the projections of the geomagnetic field lines, he considers it difficult to explain the same value of the major axis at high and low elevation of the source. For Tromsø it is expected that the change in the value of the major axis from upper to lower culmination should be still greater than in Cambridge.

5. The Drift Speed of the Irregularities.

The true drift can be evaluated from a three point receiving arrangement using the full correlation analysis. This analysis has not been possible using the present material, but we may obtain indications of the mean drift directions from the shape of the T_y- and T_x-curves during upper and lower culminations as shown on Fig. 3.

It is easy to show that the general shape of the median variations of T_x and T_y around the culminations can be explained on the basis of the following assumptions:

i) the structure of the ground pattern is stretched infinitely along the direction of the projection of the geomagnetic field lines,

ii) the ground pattern moves always towards W with a speed of the order 400—600 m/s.

The median values of T_x indicate an apparant uniform drift component V^1_x towards W of 400—600 m/s. If there is no N-S component the time delays T_y will given by $T_y = T_x \mathrm{tg}\theta$. Fig. 5 shows the median values observed and the computed values of T_y based on these assumptions.[1]

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[1] The diffraction pattern on the ground will acquire a drift due to the angular motion of the radio source, which at upper culmination will be directed towards E and at lower culmination towards W. The magnetitude of this component will depend on the angular height of the radio source and the height assumed for the diffracting screen in the ionosphere. Assuming a height of 400 km it can be shown that the rotation of the earth will introduce a drift component towards E at upper culmination of the Cassiopeia source of 16 m/s and at lower culmination of 26 m/s towards W. At very low heights of the radio source this correction will be appreciable, see [5].

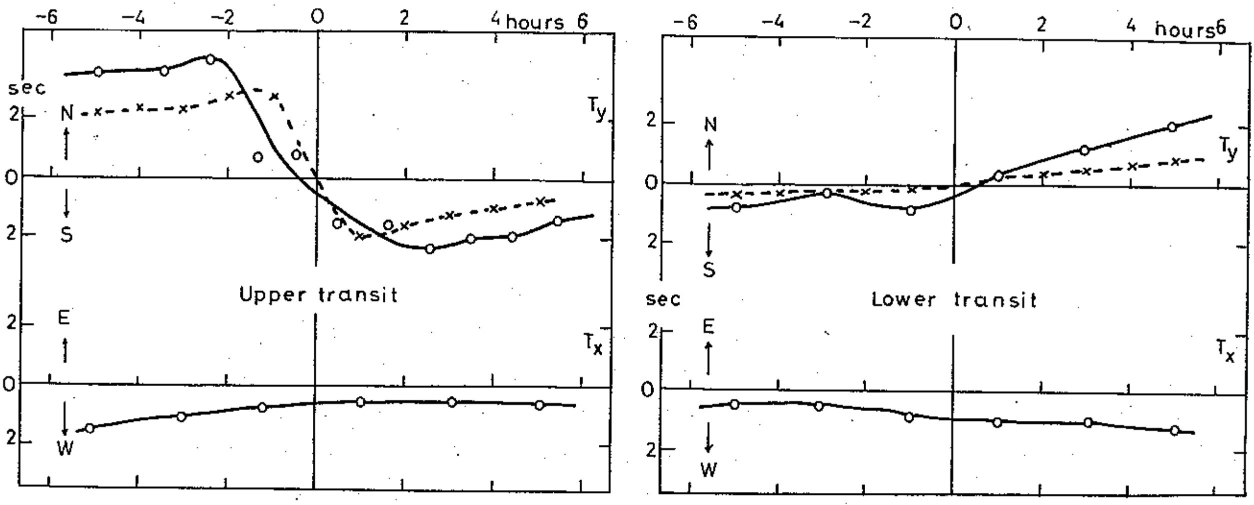

Fig. 5. The circles show the median values of the time delays *Ty* and *Tx* observed. The broken line indicate the values of *Ty* computed according to the formula $Ty = Tx \operatorname{tg} \theta$.

From figure 5 it is apparant that the general character of the variation in the T_y- and T_x-curves is explained assuming a *mean drift towards W* of an anisometric pattern which is stretched along the projections of the geomagnetic field lines as seen from the radio source.

There are, however, details which are not explained by this simple picture. There is an asymmetry both in T_y and T_x around the time of culminations as seen on Fig. 3. The values of T_y are systematically greater before upper culmination than after. This may be due to the fact that the aerial system used only partly discriminated between the Cassiopeia and the Cygnus source, and two ground patterns will thus appear, one weak from the Cygnus source and a stronger one from the Cassiopeia source which may at times move in different directions. The Cygnus source will appear at upper culmination 3—4 hours after the Cassiopeia source. Before the time of culmination of the Cassiopeia source the ground patterns from both radio sources will show a T_y-component directed towards N. After the time of upper culmination of the Cassiopeia source the ground pattern of the Cygnus source will still for 3—4 hours exhibit a T_y-component towards N whereas the ground pattern of the Cassiopeia source now will show a T_y-component directed towards S. The asymmetry in the T_x-curves is difficult to explain, it may also partly be due to influence from the Cygnus source. It is obvious that for a detailed study of the properties of the ground pattern at the times of culminations it is necessary to use aerials which are more directive than the usually used simple Yagis as elements in the interferometers.

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Appendix.

CALCULATION OF THE CORRECTION IN DRIFT DUE TO THE EARTH's ROTATION

The coordinates of the radio sources are:

Cas: RA $= 23^h21_m$, $\delta = 58.6°$,
Cyg: » $= 19\ 58$, $\delta = 40.6°$

The angular velocity of the sources will be for Cass: 8°/hour, for Cyg: 12°/hour.

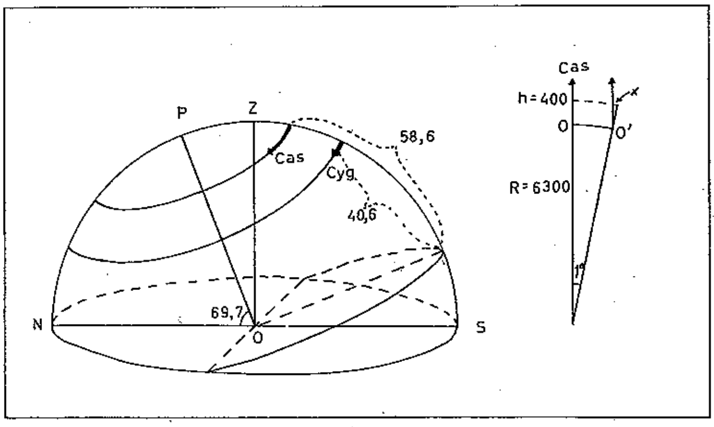

Fig. 6.

When the earth rotates 1° the place of observation *0* will be displaced to a new position *0'*. At the same time the diffraction screen, viewed from the place of observation, will be displaced a distance x from the zenith direction and in opposite direction.

According to figure 6 we will have:

$$x = Dr/R \text{ km/degree}$$

where D is the distance along the earth's surface corresponding to 1° rotation (110 km), R is the radius of the earth (6 300 km), r is the distance (range) from the place of observation to the point where the waves from the radio source cut the diffraction screen. H is the height of the diffraction screen (400 km) and h is the angular height of the radio source at the time of observation.

The drift components in E-W direction introduced by the earth's motion are given in tabel below for the Cassiopeia and Cygnus sources at upper and lower culminations.

	Upper culmination			Lower culmination		
	h	r	Vx(E)	h	r	Vx (W)
	°	km	m/s	°	km	m/s
Cas.............	78.5	400	16	38.5	650	26
Cyg	60.6	460	28	20.6	1 140	69

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