Conjugate Aurora Observations by the Gjøa and Discovery Expeditions

by
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ABSTRACT

From 1901 to 1912 - known as the 'heroic period' of Arctic and Antarctic exploration, great inroads were made not only geographic but also scientific to our knowledge of the continent. At Amundsen's Expedition through the Northwest Passage, measurements of the geomagnetic field and visual auroras were carried out for 19 months at Gjøahavn (geographic coordinates 68º 37' 10'' North (N); 95º 53' 25''West (W). Scott's *Discovery Expedition - at Cape Armitage, McMurdo* (coordinates 77.86º S; 166.69º E), Antarctica, carried out same type of measurements. Their observations were carried out geomagnetically conjugate to Gjøahavn, both stations close to 78 degrees magnetic latitude. In addition, measurements were overlapping in time during the year 1903-04. However, these two stations are located at different longitudes so there is a difference in local time between the stations of about 6.5 hours. Gjøahavn and Cape Armitage are conveniently located for separating disturbances in the polar cap regions caused by solar electromagnetic radiations or the solar wind.

Auroras were observations during seven moths per year. This gave a unique possibility to compare conjugate characteristics of polar cap auroras. Comparing conjugate geophysical data introduce some difficulties. During the winter season at Gjøahavn, they had bright summer in Antarctica, and vis versa. Thus, simultaneous temporal, and spatial ionospheric variations can be marked different. Still, the average diurnal and seasonal variations were similar. The quantity of the auroral data from Cape Armitage was larger because there they had continuous watch of the sky.
The main findings regarding polar cap auroras are:

Three different auroral forms dominate the polar cap. Low intensity auroral bands - then called streamers, were the dominating auroral form morning and afternoon. The number of auroral events in 1903 was nearly twice that in 1902 and 1904. A marked midwinter maximum was observed at both stations. Many displays were observed poleward of the oval. The large fraction was associated with weak magnetic disturbances.

Some forms of polar cap auroral have special magnetic signatures and seem to be anti-correlated with Kp. They can be mapped even if they are not seen. According to recent satellite measurements (Newell et al., 2009) they are probably caused by polar rain and/or photoelectrons.

1.0 Introduction

During the first decade of the 1900s – known as the ‘heroic era of Arctic and Antarctic exploration’, new inroads were made to the continent (cf. e.g. Huntford, 1982; Barraclough and Malin, 1981; Silverman et al., 1994; Egeland and Deehr, 2014). Roald Amundsen (1872 -1928), and Robert F. Scoot (1868 – 1912) led expeditions, pioneering geological, glaciological, and meteorological discoveries. During Amundsen’s *Gjø*a Expedition through the Northwest Passage, measurements of the Earth’s magnetic field and auroral were carried out at Gjøahavn (GH) on King William’s land (geographic coordinates 68° 37’ 10’’ North (N); 95° 53’ 25’’West (W), for 19 months. The data have now – for first time, been analyzed based on what we have learned during the space age.

During this work it was discovered that Scott’s *Discovery Expedition to Cape Armitage (CA), McMurdo* (coordinates 77.86° S; 166.69° E), in Antarctica, carried out the same type of measurements, and that there was overlapping in time with those at *GH* in 1903-04. New calculations showed that Cape Armitage was nearly geomagnetically conjugate to Gjøahavn at 78° magnetic latitude. This gave us a unique possibility to compare conjugate polar cap auroras.

1.1 The *Gjøa and Discovery* Expeditions

Amundsen’s and Scott’s knowledge of geomagnetism and auroral physics was limited, but Amundsen at least lay the groundwork for serious scientific observations when preparing the *e*xpedition. His main mentor was the Deputy-Director of the Norwegian Meteorological Institute in Oslo, Dr. Axel S. Steen and he also met with Professor Kr. Birkeland (1867-1817). In addition, he cooperated with two German experts, Professor Georg von Neumayer in Hamburg, Director of Deutsche Seewarte Institute, and Professor Adolf Schmidt at Potsdam Observatory. Together with one of his crew they made three trips to Hamburg and Potsdam, Germany. He also travelled to Birkeland’s observatory at Bossekopp, in Northern Norway, to learn about geophysical observations. His diary from this Expedition (Kløver, 2017a; Egeland and Deehr, 2014) contains some interesting auroral observations and comments regarding the connections between auroras and geomagnetic disturbances.

Scott’s science background and interests for space physics was less. As far as we have found, he never looked on the data. Scientists at the Royal Academy in London were responsible both for the field measurements and the first preliminary presentation (cf. Chree, 1909; Bernacchi, 1908).

As Figure 1 shows, Scott’s *Discovery Expedition at CA* was located conjugate to GH, but there is a difference in local solar time between the stations of about 6.5 hours. Because of this location, disturbances caused by solar electromagnetic radiations, or the solar wind can be separated.

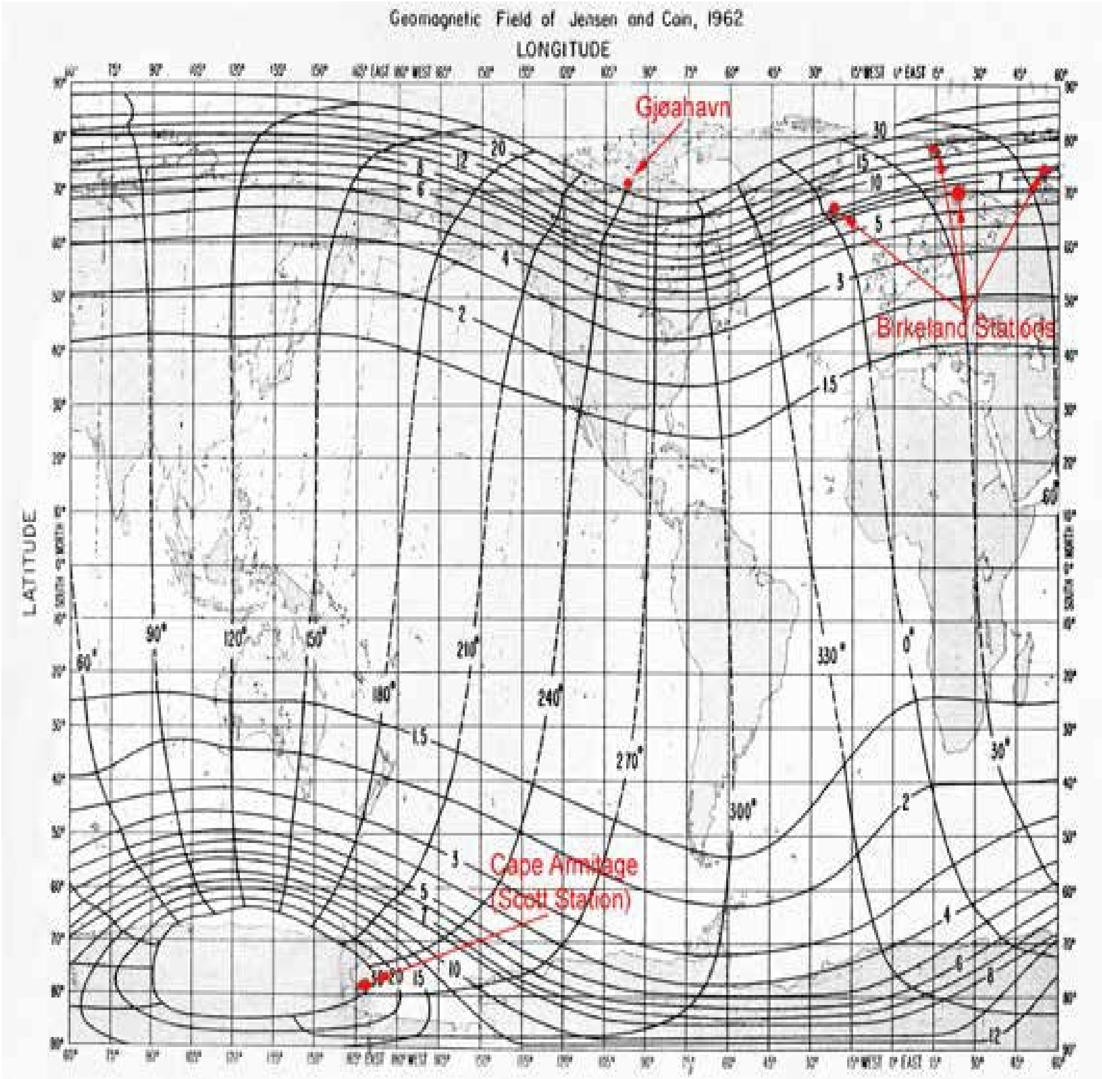

Figure 1. The figure shows the Earth's magnetic field coordinates at the surface superimposed on a map of the world in rectilinear geographic coordinates. The magnetic longitude – the numbers with the degree mark, is given in degrees east from the point where it intersects the Greenwich meridian. The magnetic latitude close to the poles is also given in «L- values». These are integer numbers in Earth radii of the distance from the center of the Earth to the point where the field line intercepts the geomagnetic equator (Egeland and Deehr, 2014).

For interpretation of auroral observations it was discovered – around 1950, that it was an advance to use a coordinate system based on the geomagnetic field and magnetic time. Such a system is briefly presented.

The Earth's magnetic latitudes and longitudes are referred to a system with the z-axis along the geomagnetic dipole axis through both magnetic poles, which is inclined 11 degrees from the geographic pole in the north hemisphere, and the 180-degree longitude – also called the geomagnetic meridian, goes through both the geomagnetic and the geographic north pole. The latitude circles from 0 – 90º north (N) and south (S) are perpendicular on the geomagnetic meridians.

Local solar time (LT) is defined by the location of the geographic longitude of the station with respect to the Sun, while universal time (UT) is referred to a geographic system with the 0-meridian through Greenwich. At local noon and midnight UT the longitude of the observer is aligned with the Sun and the geographic 0º- and 180º meridian through the geographic pole.

We here compare observations from stations in opposite hemispheres. So rather than consider the station in the Southern Hemisphere, as 11 hours ahead of Greenwich (UT), we refer to this station as 13 hours behind in UT and 6.5 hours behind GH, which itself is 6.5 hours behind in UT.

The intensity and the direction of the Earth's magnetic field is continuous, but slowly changing. Based on a new geomagnetic refence field (1969.75 IRGF), the geographic and geomagnetic coordinates for years 1905 and 1970 for the two stations, have been recalculated. These calculations show that the magnetic coordinates of CA and GH have changed less than 2 degrees west in longitude (10 minutes) and 0.25 degree of latitude (equivalent to ~25 km) relative to one another from 1900 to 1970.

Station	Time	**Mag. Noon**	**Mag. MdNt**	**SS Onset**	**SolarNoon**	**Solar MdNt**
Gjøahavn	UT	19:30	07:30	06:00	18:24	06:24
	Local Solar	13:00	01:00	23:30	12:00	00:00
Cape Armitage	UT	19:00*	07:00*	05:30	23:06	11:06
	Local Solar	08:00	22:00	18:30	12:00	00:00

**The station Cape Armitage may be 15 to 60 min east of Gjøahavn in magnetic time.*

Table 1. A list of UT, Local Solar Times, Magnetic Midnight, and Magnetic Noon, and Average Auroral Substorm - SS Onset for the two Observatories.

Magnetic midnight and noon are the local times when the station passes through the plane containing the Sun and the geomagnetic pole at night and day, respectively. Thus, magnetic midnight occurs near 07:30 UT and at 01:00 local time (LT). The most dynamical changes and poleward expansion in the auroral zone normally occurs between 22:00 MLT and magnetic midnight.

2.0 General about Aurora

Around 1900, the study of aurora was still an emerging science. The main question at that time was the relationship of the aurora and magnetic disturbances (Birkeland, 1908).

In his lecture to the Norsk Geografisk Selskap (The Norwegian Geographical Society), on 25 November 1901, Amundsen (1902) presented his plan for '*The Voyage Through the North West Passage'* (Kløver, 2017a; 2017b).

Amundsen had read Sophus Tromholt's (1885) book, *Under the Rays of the Northern Lights* and had visit Birkeland in his famous Terrella laboratory at the University. Nansen's (1897) drawings of northern lights from the *Fram* Expedition were well known. Auroral observations at those high latitudes were unprecedented.

Aurora around the 19-century was only subjective to observations with your naked eyes - i.e., visual observations. The pragmatist Amundsen included auroral observations before bedtime in his daily station activities.

Some basic new auroral facts learned during the space age, will briefly be mentioned.

Spacecraft - after 1960, gave us the opportunity to explore space between the Earth and the Sun with in-situ observations. With Explorer 1, launched in 1961, the first measurements across the near-earth space – called the magnetosphere, were carried out. Interplanetary space, not long ago believed to be empty of matter, was filled with streaming electrons and ions of solar origin. These streaming particles, called the solar wind, were for the first time observed during the 1960s. The solar wind is the important connecting link between solar activity and geophysical disturbances. The interplanetary magnetic field (IMF) is an extension of the solar magnetic field carried by the solar wind as the plasma leaves the sun (Kivelson and Russell, 1995).

3.0 The Auroral Observations at Gjøahavn

The map in Figure 3 illustrates the location of GH Observatory relative to both the geographic and the magnetic north pole, the Artic Circle as well as the location of the new auroral station at Spitzbergen.

Aurora occurrences before the space age were normally referred to the Fritz' (1881) auroral zone, with maximum round 67 degrees magnetic latitude - or 23^{o} from the magnetic poles. The Gjøahavn station is located close to 78^{o} magnetic latitude.

Observations were carried out from late September to early March by Peter Ristvedt (Kløver, 2017b). Ristvedt's original auroral handwritten notebook is not easy to read, but Aage Graarud (1932) translated his notes into English, word for word. The first page in Graarud's version – out of four, is shown in Fig. 2. Amundsen reported 15 events in his diary (Kløver. 2017a) in addition to those listed by Ristvedt.

No official classification of different auroral forms existed then. The first aurora atlas was not published before 1930, by Carl Størmer (1930; 1955). All data from this expedition are stored by Videnskabs-Selskabets Skrifter, No. 3, in Oslo (cf. Norwegian Geophysical Committee, 1920).

Following terms were used in the auroral protocol:

Streamers/strips, which have been taken to mean active auroral rays.
Band(s); seem to be a common name for both arcs and bands.
Crown; is interpreted as corona.
Auroral clouds; large surfaces of lights.
Auroral patches; this form is not defined, but is probably like clouds, but smaller.

Words as 'auroral fire, flaming auroras, flickering streamers of lights are also listed in the original protocol.

Observations of Aurora Borealis.

arears	Days	Hours	Aurora Borealis.
1903	November 4	5 30 p.m.	Streamers from SE to zenith.
» »	» 8	6 »	Green, magnificent bands from SE to zenith.
» »	» 10	5 30 » — 6 20 p.m.	Faint streamers and bands, frequently and briskly changing.
»	» 11	5 20 » — 6 30 »	Faint streamers, S—SW.
»	» 12	3 a.m.	Faint streamers and bands, SE, SW, hor. to zenith.
»	» 12	6 p.m.	Faint horizontal stripe at the south horizon.
»	» 12	11 »	Faint streamer in the south.
»	» 12	12 »	Faint stripe S to W ca. 30° above the horizon. Thick mass of clouds at the base.
»	» 13	12 »	Very faint streamers from the horizon, ca. 45° towards the zenith.
»	» 14	10 »	Cloudlike aurora in S and W, ca. 30° above the south horizon, ca. 10° above the W-horizon.
»	» 14	11 »	Aurora in S and SW, 20° above the horizon with dark clouds underneath, a single streamer 60° towards the zenith.
»	» 14	12 »	Bright stripe SE — N, at the highest 30° above the horizon.
»	» 17	8 20 »	When going from ship, we saw a luminous beam above our lodge, and believed that this was on fire, but reaching the top of the hill we saw the light to be an aurora in the S. It had the shape of a large fire on the ice between us and the horizon. Gradually the streamer lengthened along the ice as far as to the W. Then flickering streamers commenced to stretch towards the zenith. At 6^h 15^m p.m. growing fog hindered further observation.
»	» 17	10 »	Faint aurora in W, vague in form.
»	» 17	11 »	Very faint aurora in W.
»	» 17	12 »	Widely spreading aurora, but still faint, with its centre at the W-horizon, from there sending streamers towards the zenith. In the northern sky a faint aurora of vague form. Only in S the sky was clear.
»	» 20	8 30 » — 9 p.m.	Strong belt from the S hor. towards SW, altitude ca. 20°.
»	» 22	5 30 »	Faint stripe from S to W horizon.
»	» 23	6 »	Faint aurora as streamers from the S and SW hor. towards the zenith. Ca. 45° high.
»	December 8	9 »	Strong flashing zigzag beams from the SW hor. through the zenith to the E horizon.
»	» 8	11 »	Faint streamers in S.
»	» 9	3 30 »	Faint, bright streamers from the S hor. towards the zenith, ca. 30° high.
»	» 10	5 30 »	Aurora as a faintly flickering flare in the SW horizon.
»	» 15	5 » — 9 p.m.	Arch S—W in SW ca. 15° high.
»	» 17	4 30 »	Very strong aurora as streamers SW-NE through zenith.
»	» 17	5 30 »	Still strong streamers, but on the zenith several larger and smaller spots in lively motion.
»	» 17	9 »	Very faint, hardly visible pavilion in the zenith.
»	» 18	5 » — 9 p.m.	Stripe SW-WNW. Some faint and frequently shifting points at zenith.
»	» 21	5 30 » — 8 40 »	Bands through zenith all around the horizon.
»	» 24	1 a.m.	Very strong band S-WNW ca. 30° above the horizon. From SW a streamer to zenith, fading away towards the zenith, where it wholly disappeared.
»	» 26	11 30 p.m.	Faint streamer from N to zenith, where it entirely went out.
»	» 30	8 a.m.	Strong zigzag band from N hor. to zenith, frequently changing to flickering streamers that rapidly died away.
1904	January 5	5 p.m. — 6 p.m.	At hor. S-W. On the SW a faint streamer to the zenith.
»	» 5	10 »	Strong flickering streamers SE-WNW, stretching from the hor. to zenith, there forming a pavilion (aur. corona).
»	» 6	4 30 » — 9 »	Bands and zigzag streamers at the hor. ESE-NW stretching to zenith, rapidly shifting in power and colour. Greatest intensity between 5^h and 5^h 30^m.

- *Figure 2. One page of Graarud's (1932) collection is shown. Important events – year, dates, and times, are briefly commented on in the text.*
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Amundsen shows scientific effort for the observing program, but few recordings are included in his book *The Northwest Passage* (Amundsen, 1908), except the once connected with the drift of the magnetic north pole since Ross (1834) measurements in 1831. They are further summarized in his lecture at the *Royal Geographic Society*, London on 11 February 1907 (Amundsen, 1907).

However, Amundsen appointed a committee consisting of Dr. Aksel S. Steen, Deputy Director at The Norwegian Meteorological Institute, as chairman, while Dr. Wasserfall and the meteorologist N. Russeltvedt were the other two members. In fact, the editing and preparation of the observations were not complete until 1933 (Steen, Russeltvedt, and Wasserfall, 1933). Northern lights poleward of the auroral zone are called polar cap auroras. Hardly any documentation of this type of auroras existed when these expeditions were carried out. As a clever expedition leader, Captain Amundsen knew the value of keeping day-to-day records. However, the instructions indicate that visual monitoring of aurora did not have the highest priority. Fortunately, the detailed diaries of the crew members have now been published (Kløver, 2009, 2017a; 2017b, 2017c).

The dataset has limitations because: 1) observations were not carried out around the clock, 2) no illustrations or sketches exist, and 3) the available descriptions are scanty. During the epic voyage through the rest of the Northwest Passage to Alaska, they also observed some displays, but they are not included here.

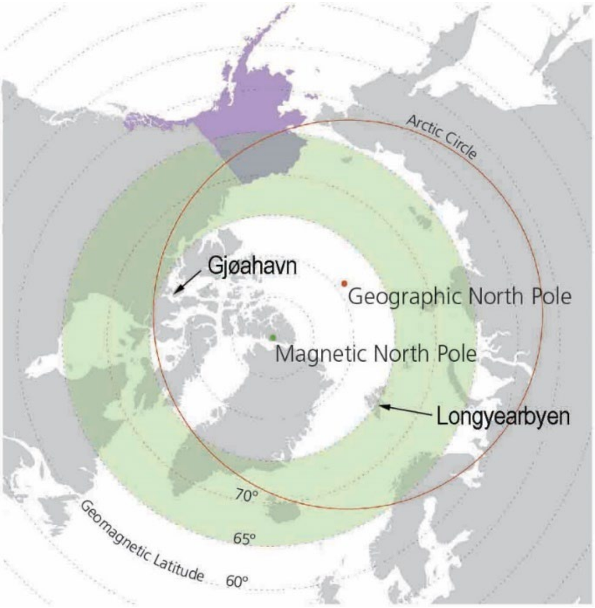


Figure 3. A map of the Arctic region where the locations of Gjøahavn, the magnetic and the geographic poles are marked.

3.1 Scientific Results of the Gjøahavn Auroral Observations

The text for the first event on the 4th of November 1903 is: *Streamers of northern lights from southeast (SE) to the zenith (Z), were seen in the early local evening (from 5 pm.).* In Amundsen's diary (p. 124), it is listed that the temp. was - 25° C, and he *saw 'northern lights from early afternoon. They appear as a semi-circular formation approximately 30° above the southern horizon. 5 rays stretched to the zenith from the semi-circular formation. The rays came and disappeared, intermittently. These lasted about a quarter of an hour and then disappeared. I also saw a fan-shaped clouds to the NW.* The magnetic record for the 4th to the 5th of November, is shown in Figure 5.

This event is illustrated in Figure 4. The regular oval auroral oval - 30° above the southern horizon, together with three arcs stretching poleward from the oval, are shown.

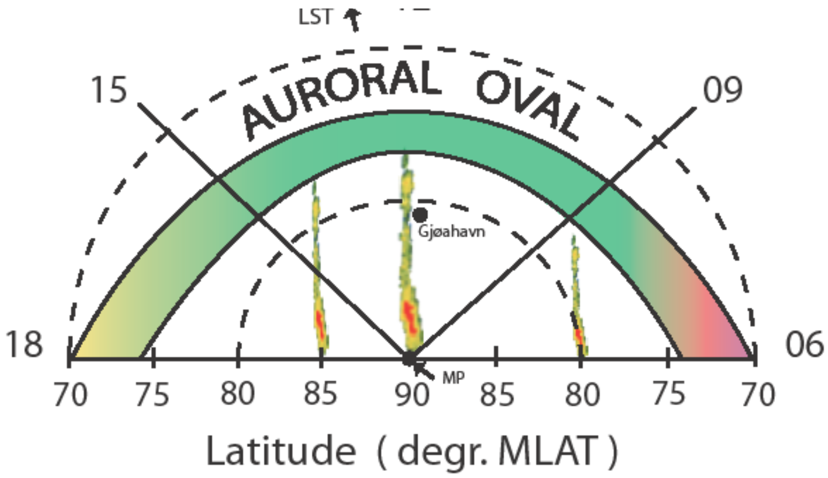


Fig. 4. *This is a schematic illustration of the aurora on 4th November 1903 at GH, in magnetic time (MLT) and magnetic latitude (MLAT), covering the region from the magnetic pole (MP) to 70 degrees north. The viewing perspective is the polar upper atmosphere with the oval – in yellow green, from 06, via noon to 18 MLT. The direction to the Sun is up in the figure. The location of GH is marked. Three reddish sun-aligned-polar arcs stretching from the oval past the zenith, are shown.*

Thus, this auroral event started before magnetic noon. When the intensity of the lights changed rapidly and moved poleward, some small magnetic disturbances were recorded, as shown in Fig. 5.

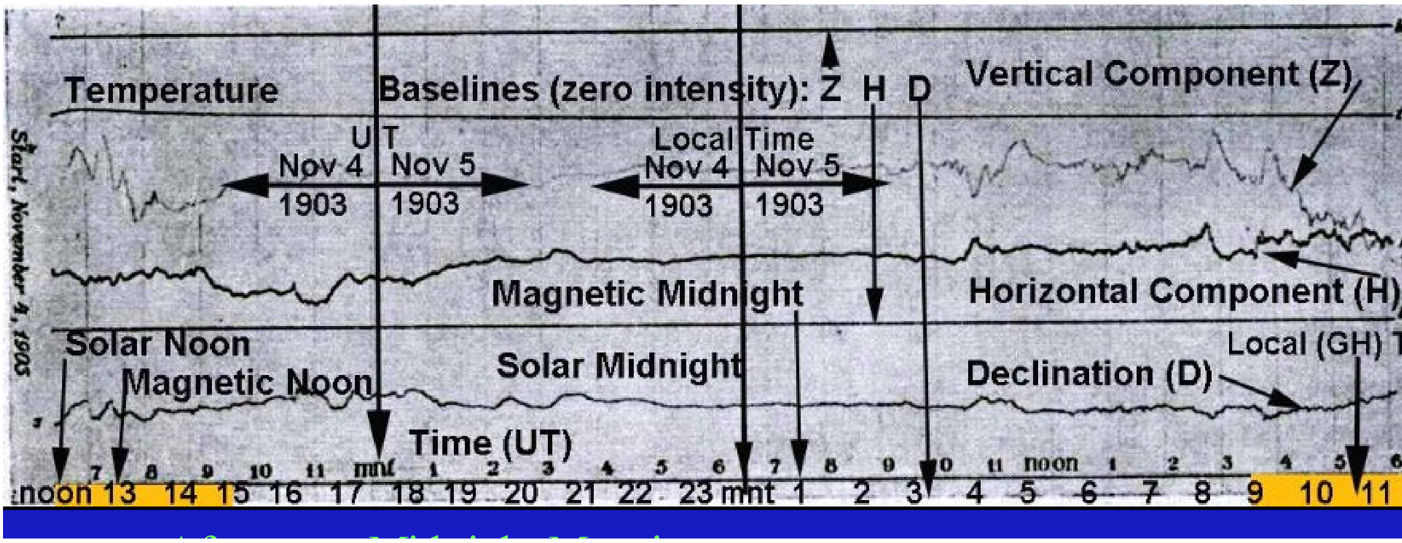


Figure 5. The magnetic field recordings - as function of time in UT, from the 4th to the 5. November 1903. The three curves - marked Z, H and D, illustrate the vertical, the horizontal and the declination components of the magnetic field. The upper curve shows the temperature in the recoding hut and the baseline, while the bottom curve gives the hours. The vertical scale illustrates the magnetic intensity in nT. The photosensitive paper used for the recordings was changed daily near 6 UT, i.e. near magnetic noon. Notice that the magnetic activity is very low around magnetic midnight. The original magnetogram has been redrawn to show more details including Magnetic noon and midnight.

The mistake of identifying an auroral event as a fire, indicates that these *luminous beams* had a marked reddish colour. The emperor Tiberius, in the year 37 A.D., ordered a troop of solders to rescue the village of Ostia which was reported to be on fire. It was an unusual fire seen from large distance, which was 'an auroral fire'. There are a few more recent examples of "auroral fires". The one reported from London on the 15th of September 1839, when the whole sky was one vast sheet of reddish light, is well documented. It had a most alarming appearance.

An 'auroral fire' was also reported at GH. According to Amundsen – p. 134 in the diary, the northern lights on the 14th of November lasted passed midnight. This event was observed by the crew who were out reindeers-hunting. The temperature was – 20° C. On their return they saw a big reddish display in the sky and were afraid the whole camp was on fire. Quote: "We saw the luminous beam above the lodge, and believed that the camp was on fire, but reaching the top of the hill, we discovered the light to be aurora. It had the shape of a large fire on the ice between us and the horizon. Near midnight aurora was sending up streamers toward zenith".

Northern lights were also observed on the 18th, 20th as well as on 22nd and 23rd November, but without magnetic activity.

During the first Christmas Eve '*a strong band of northern lights ~ 30° above the southern horizon';* was seen. In addition, streamers of lights reaching the zenith, were observed. This is an event like the one mentioned on the 4th of November. The activity lasted from early afternoon to after local midnight. Amundsen was surprised - p.151 in diary, *as* he wrote: *The strong aurora I saw at Christmas, was almost with no geomagnetic disturbances*. Regarding the auroral event he wrote: *Very strong aurora as streamers SW- NE though zenith is seldom. Later in the afternoon, strong auroras were seen near zenith. Several larger and smaller spots in lively motion with hardly any magnetic disturbances*.

In the diary on page 172, Amundsen wrote: We saw active northern lights over the whole sky on the 8th of February and it lasted three days. They seem to come from all directions. Around midnight the lights spread over large part of the sky, and faint auroras were even seen all up to the north. No auroras were seen in the south. Strongest auroras in the western horizon with poleward moving up to zenith, are mentioned. They appear one moment and disappeared the next. As the rays were deep reddish, it may indicate an observation of Sun-aligned-arcs. The arcs were most clearly seen on the darker eastern part of the sky. These observations were carried out two hours before magnetic midnight. The day after Amundsen wrote: 'The northern lights I observed yesterday have slightly disturbed magnetic activity.

February 1905 was also an active period with auroras five days in row. For one event the text is: Aurora in SE to NW, brisk motions, sometimes dispersed over the entire sky and with much deeper colors.

The last observation from Gjøahavn is on 2nd March 1905. Aurora is seen all over the entire sky from a strongly bright pavilion in zenith.

Total numbers of nights per months and years when auroras were observed, are shown in Table 2.

90 events were recorded. The overwhelming number of events were of moderate or low intensity. 26 out of 90 events extended zenith. Only on 7 of the 90 events were color listed. Most dynamical changes and poleward expansions of auroras normally occurred between 22hr MLT (cf, Ch. 6.2) and magnetic midnight. Polar cap auroras were visible from magnetic noon in December, i.e. from 1300 LT, but few observations were listed before after 1500 LT.

Year/ month	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1903 30	1	3	13	13	-	-	-
1904 45	0	5	12	8	11	6	3
1905 15	-	-	-	-	8	5	2
Totals 90	1	8	25	21	19	11	5

Table 2. Total number of auroras per months and years, observed at Gjøahavn. The events reported in the diaries by all crewmembers have been included. Thus, this table is different from the one by Graarud (1932).

4.0 Auroral Observations at Cape Armitage

The observations were led by L. C. Bernacchi (1908), but carried out around the clock by 'the meteorologist on duty with a check every hour'. Dr. Bernacchi was called up when significant, large auroral sightings were observed. Even if the observers were at outlook for 24 hours per day, the conclusion is 'still some faint or moderate bright auroras might have failed to be noted'. A similar auroral classification as at GH is used. Regarding auroral intensity, the conclusion is: 'Their brilliances were rarely more intense than stars of the 4th magnitude or the Milky Way'.

Luminous patches - sometime small and at other times occupying almost the whole sky, which frequently looks like the appearance of clouds, are mentioned. Streamers are often listed and can represent different forms. Several vertical rays close together, similar to the form Størmer (1930) called *draperies*, are mentioned. Spectral observations were tried, but no results reported, even if long time integration was tried.

Arcs and bands touching the horizon at both ends were rarely seen. The aurorae were particularly visible during the dark moon periods. During exceptional extensive displays, Bernacchi called Mr. Edward A. Wilson, the expedition junior surgeon who also was an artist, to clearly see the largest displays. Wilson contributed with two dozen charcoal drawings of aurora australis. From these sorties, one is shown in Figure 7.

Table 3. The recorded auroral events for different months in 1902 and 1903 are listed. As the table shows auroras were recorded between March and September- particular many in

TABLE showing Number of Days in each Month when Auroræ were Recorded.

Year.	March.	April.	May.	June.	July.	August.	September.	Total.
1902	0	10	8	11	10	9	4	52
1903	2	18	14	18	22	14	2	90
Days. . .	2	28	22	29	32	23	6	142

1903. The main activity was found both years during June and July (Bernacchi, 1908). Surprisingly, few auroral events are observed in May both years, even less than in April.

Notice that the number is significant higher – nearly double, in 1903 compared to 1902. Maximum occurrence was recorded both years mid-winter. The activity is very high in April both years, while the numbers of days with auroras are nearly equal in both May and August. Notice that more events were even seen in April than in May. This confirms well with what was found at GH and prove clearly that aurora is a very dynamic phenomenon.

The year 1903 was special with the strongest magnetic storms on 31st October during that century. It is interesting to notice that a similar series of storms - called the Halloween storms, were recorded 100 years later. Is it just a coincidence?

4.1 Scientific Results of the Auroral Observations at GH and CA

Two main objectives are achieved by submitting the GH and CA data to modern analysis:
Firstly, to compare these old data - both in quality and accuracy, with those observed late in the 20th and early in the 21st century.
Secondly, to check the Sun's and solar wind activity and its influence on the Earth several decades before these processes were directly discovered.

Since the 1950s auroral observations have been carried out continuous at many auroral observatories and the statistical locations of the auroral ovals have been safely established. Its location – both in north and sought, for moderate disturbed conditions – K_p =2 and different local times, is shown in Figure 6. The red sector of the oval illustrates when daytime auroras dominate.

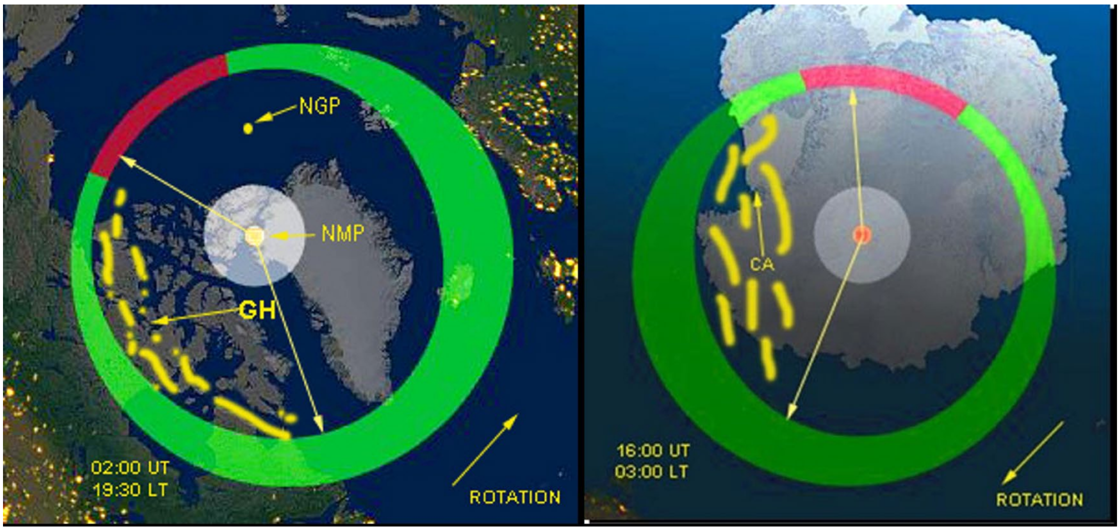


Figure 6. This figure illustrates the location of the Arctic and Antarctic auroral oval during moderate disturbed magnetic condition [Kp at both stations around 2] according to Breedveld (2020) and Sigernes et al. (2011). The locations of the two stations GH & CA are marked. Approximately 30 % of the events are observed poleward of the oval. The rotation direction – marked by the yellow arrows, is opposite in the two hemispheres. The figure is based mainly on ground observations. Low intensity auroral yellow bands observed mainly in the geographical western hemisphere – called 'Sun-aligned Arcs', were the dominating auroral form poleward of the oval at both GH and CA. This form was in average nearly observed each second night.

The accurate location and extend of the oval depend on several different scientific processes in this dynamical region. The measurements at GH and CA clearly show maximum occurrence during midwinters at both hemisphere and its connection with magnetic disturbances is low, which show that our data are observed poleward of the oval. This also indicate that the production source of polar cap auroras is different from those oval auroras.

One of the charcoals auroral drawings from CA is presented in Figure 7. To the author it looks like a nice folding curtain drawn by A. Wilson when he looked at the display.

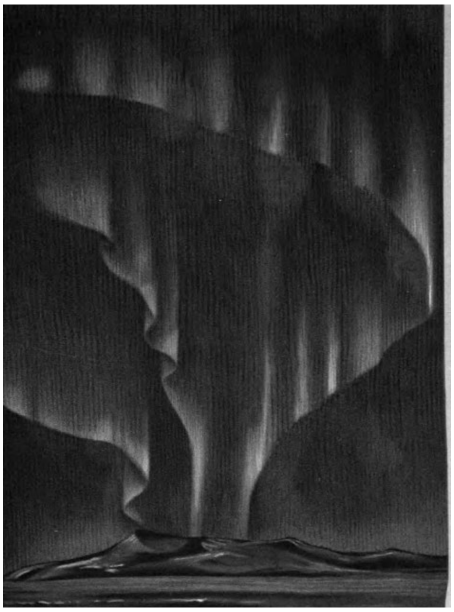
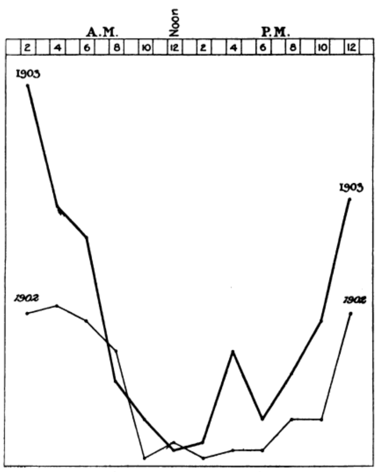


Figure 7. A charcoal rendering of the aurora observed at CA on April 9th, 1902, at 0225 am LT of an event classified as streamers from north with intensity as a star of magnitude 3. Its title is "Auroral Streamers". Copied from Bernacchi's (1908).

5.0. Daily variations in the occurrence of auroras at CA and GH

The average diurnal variation of auroral events at CA for the two winters 1902 and 1903, is shown in Figure 8. This sighting reveals that a large fraction was observed as poleward expansions from the auroral zone. Weather and moonlight tend to decrease the number of dayside auroras. According to Bernacchi (1908), 'many of the observations were made when the magnetic curves were quiet, or even very quiet'.

Figure 8. The average diurnal variations of auroral occurrence versus local time are shown



Curves showing diurnal frequency of auroræ.

for the winters 1902 and 1903 (Bernacchi, 1908). Maximum was observed both years between 10hr pm. to 04 am. The curve for 1903, clearly illustrates a second maximum during early afternoon. The peak around 3 and 4 local time overlaps with low energy electron precipitation observed by auroral rockets in northern Norway. The number of events is listed in Table 3.

According to Bernacchi1(908) the time of occurrence appeared to depend upon the latitude where the displays were observed. If the events happened closer to the pole, it usually started to appear earlier. Maximum was first observed in the region which first got dark. Several events north of the auroral zone were observed early afternoon. During the other months it was too much daylight for auroral observations. That many more events were observed in 1903 than in 1902, is explained by the fact that the number of sunspots was higher in 1903; namely 53 compared to 24 spots in 1902 (Chree, 1909). Up to 1960, a close connection between auroral occurrence and sunspots were reported in many publications, but that has changed during the space age.

Regarding interpretation of the observations, Chree (1909) discussed electric atmospheric currents in the following way: 'The existence of very bright auroral band or streamers may mean an electric current of unusually high intensity contribute'.

The average diurnal variations at both stations are shown in Figure 9. The data from GH are in blue while the CA measurements are in red. The number of auroral days is given by the left vertical scale. Local afternoon (Aft), magnetic noon (Noon), and magnetic midnight (Midnt) at both GH & CA, are marked. The bottom yellow, horizontal line illustrate when observations were not possible at CA – because of too much sunlight, while the blue, horizontal line illustrate that systematic auroral observations at GH were not carried out after 22 LT. The two stations are 6 hours separated in local time, and magnetic time rotates in opposite directions in the two hemispheres.

The diurnal variations follow closely local solar time with a marked maximum near local midnight. The GH data also show high activity early afternoon – when we observe the sun-aligned arcs. Aurora around magnetic noon – called daytime auroras, were observed. At GH it was too much sunlight near magnetic noon to carry out observations. The observations indicate that the polar cap auroras - with maximum occurrence during midwinters, contribute significant to the total occurrence. In addition, the relations between auroral occurrence and magnetic time is different from what has been observed in the auroral oval (cf. e.g. Sandholt et al., 2005).

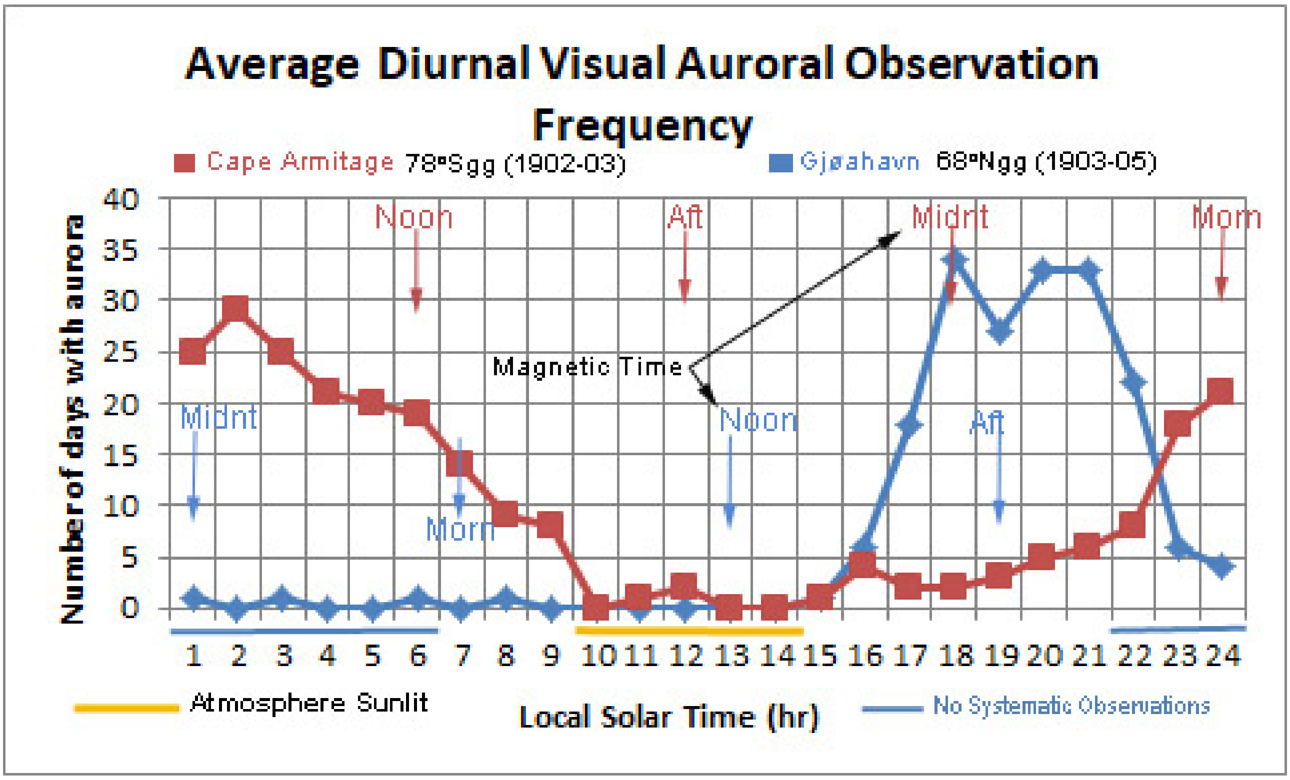


Fig. 9. The average diurnal variations in auroral occurrence at GH in blue curve, and at CA in red, as function of local solar time, is shown. The number of days with auroras is given by the left vertical scale. The times for local afternoon, magnetic noon, and magnetic midnight, are marked. The bottom yellow, horizontal line illustrate when observations were not possible at CA – because of too much sunlight, while the blue, horizontal line illustrates that no systematic observations at GH were carried out between 22 and 12 LT (from Egeland and Deehr, the 'Fram project'), recommended for publication in 2025.) The stations are 6 hours separated in local solar time. When disturbances are 6 hours separated between GH & CA, solar electromagnetic radiations are likely the important sources.

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The correlation with magnetic disturbances is low, different from than found for oval auroras. Maximum occurrence is found several hours after magnetic midnight. Thus, *these* data indicate that the diurnal variation is not controlled by the solar wind, but that photoelectrons are important.

6.0 Magnetic signatures of polar cap auroras

Observations of visual auroras requires dark nights. Even if observatories on both hemispheres are caried out, auroras can only sporadic be recorded. It has therefore been investigated if it is possible to establish a relationship to geomagnetic signatures. Then the magnetic signatures could be used as proxies for the occurrence of certain auroral forms. Three different auroral forms dominate the polar and they are discussed in the following sections.

6.1 6.1 Theta polar cap arcs (TPA)

The form called *theta* aurora was observed first in the 1980's when we got satellite photographs of the entire polar sky. The name theta was early chosen because - with an arc stretching from one side of the oval to the other, this form is like the Greek letter theta (cf. Fig. 10). Thus, the arc has a 'noon to midnight' alignment. The arc across the polar cap has a definite orientation in the sun-earth direction. This theta form is now general called 'transpolar arc' (TPA) in international literature. These arcs are primarily excited by low energy - < 100 eV, electrons (Sandholt at al., 2005). This conclusion is based on many satellites recordings. Excited oxygen atoms above 200 km are yielding weak reddish aurora at 630 nm, and virtually no emissions below. This form of aurora are generally not associated with magnetic disturbances on the ground. Because its intensity is low, this auroral form is very rarely seen by the naked eye. From ground only a small part of the theta form can be seen because a large part of the form is stretching outside the field of view of the observers.

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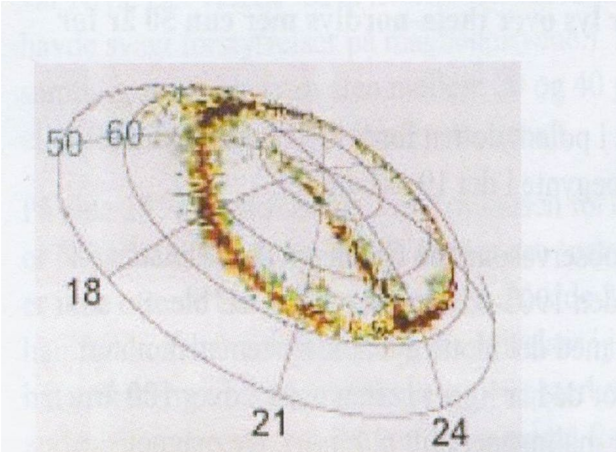

Fig. 10. *Picture of theta aurora at the northern hemisphere – as function of latitude and time, taken by IMAGE satellite – in 2002. The sun is in upper part of the picture. (Photo; NASA).*

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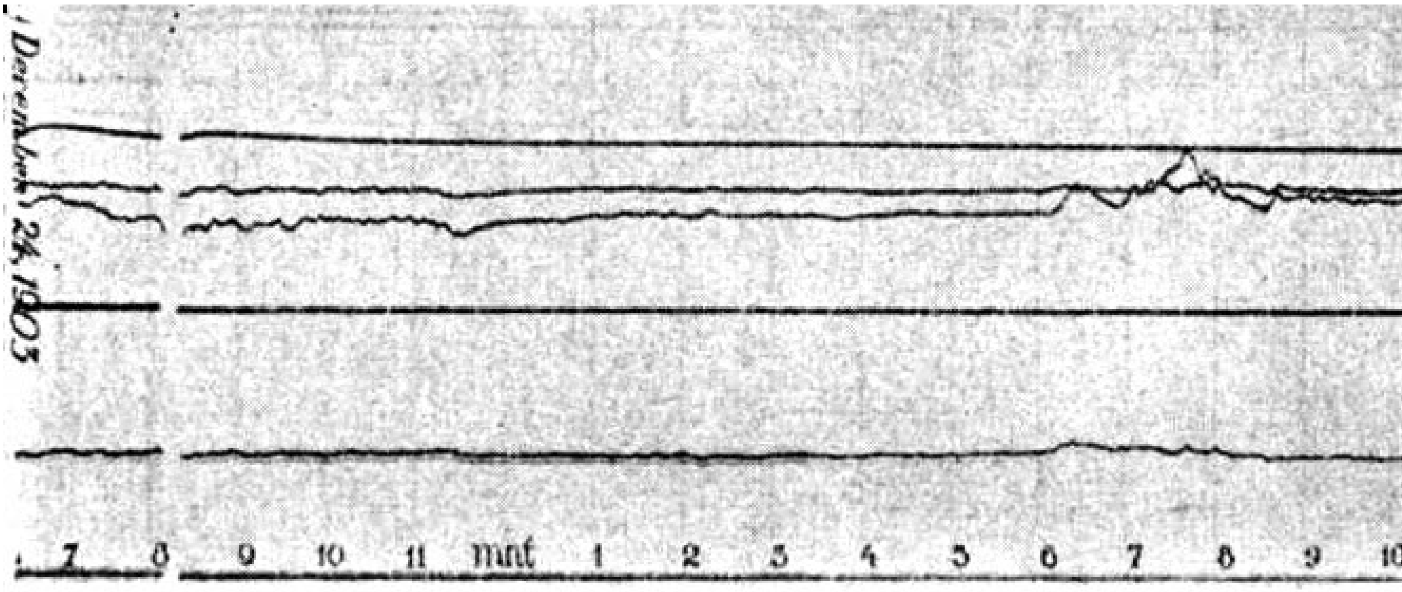

Figure 11. The magnetic recording at GH of a TPA form shows no magnetic activity in the

D- and H-component, but some weak disturbances can be recorded on the vertical component, as shown in the figure.

6.2 *6.2 Poleward moving substorm arcs (PSA)*

Also, this form is seldom seen by the naked eyes, but the magnetic substorm can be marked, as seen in Figure 12. On the 14th December 1903, near 2230 local solar time (see figure below), a poleward expansion form associated with the onset of an auroral substorm – both at GH and CA, one hour before magnetic midnight, was recorded.

Similar magnetic substorm effects of poleward expansion of auroras were observed simultaneously in 1903, a few times in both hemispheres, near 22hr MLT.

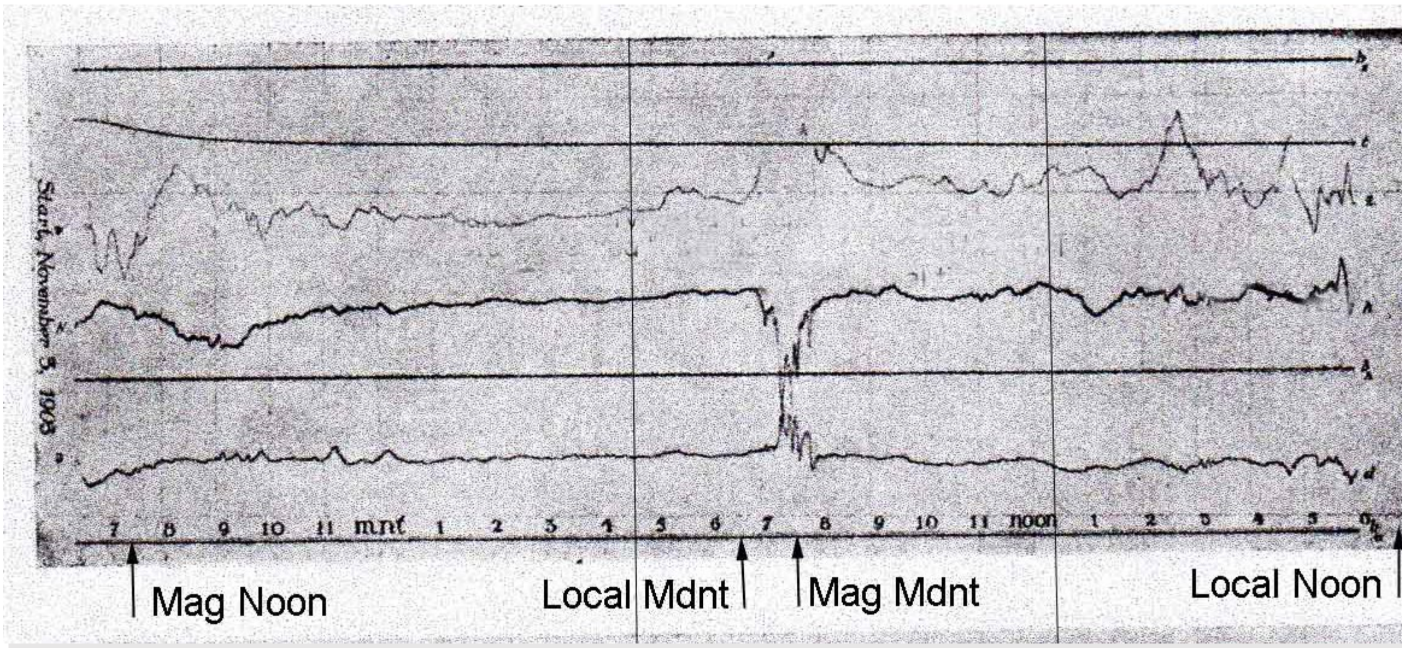

Figure 12. This magnetogram from GH shows the auroral substorm with disturbances in all three components near magnetic midnight, or at 7.30am UT. This recording is typical for relatively small auroral substorms. Similar auroral substorms have been observed at both stations during the occurrence of PSA auroras, and they are mentioned in the paper by Egeland and Deehr (2014).

6.3 Sun-Aligned Auroral Arcs

Low intensity auroral bands poleward of the oval – called Sun-aligned auroral arcs (SAA), are often observed in the polar cap. The occurrence of such auroral form is illustrated in Figure 6 by the yellow-green strips. They are the overwhelming number of auroral forms which can be observed by the naked eye poleward of the oval. However, no such forms are observed +/- 2 hours around local midnight. Magnetic recording for such events (see Figure 5) shows that the magnetic activity is extreme low around solar midnight, while some activity may be observed both before and after. As we have no drawings from CA of this form, a satellite picture from has been used for this SAA-illustration. Location is pointed out by the arrow. This SAA - recorded from a satellite, is shown in Figure 13. Notice that this arc is located well poleward of the oval.

SAA occur almost daily, as a part of the geomagnetic solar quiet variation – called the Sq variation. They appear to be emanated from the merging of the interplanetary magnetic field (IMF Bz). The intensity of the SAA and the annual, diurnal and solar cyclical occurrence frequency suggest that they are embedded in “polar rain” and dependent on the density and energy of local photoelectrons.

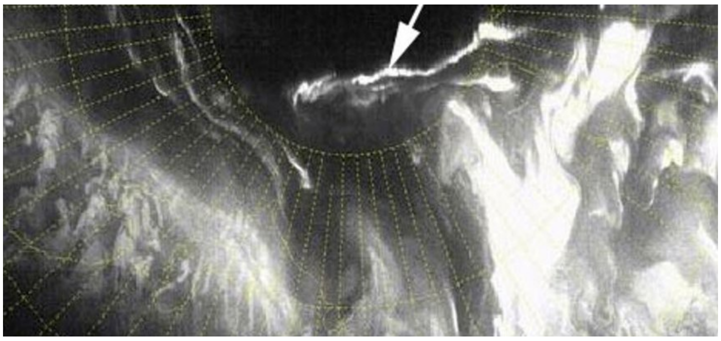

Figure 13. Example of a sun aligned auroral arc, north of the oval – marked by an arrow in the picture. The picture is taken from a DMSP satellite (Egeland and Deehr, 2024 in the Fram project, not published yet).

7.0 Summary and Conclusions

The *Gjøa* and *Discovery* Expeditions to the northern and southern polar caps (1901-1906) carried out visual auroral and geomagnetic observations from Gjøahavn (GH) and Cape Armitage (CA). These unique stations were geomagnetically conjugate to within less than one degree of 78° geomagnetic latitude and 30min of geomagnetic time (cf. Fig. 1). CA is 6.5hr in solar time behind GH. During mid-winter conditions at GH, they had midnight sun at CA. The Discovery data were organized by the Royal Society in London, and preliminary results were published in internal reports nearly twenty years before the GH data (cf. Chree, 1909; Steen et al., 1933; Egeland and Deehr, 2014). These observations have not received much attention.

At the beginning of the 20th century, it was generally concluded that when auroras appeared overhead, the earth’s magnetic field is disturbed (cf. e.g. Tromholt, 1886; Birkeland, 1908; Chapman and Bartels, 1940; Størmer, 1955; Chapman, 1968). On page 141 in his diary Amundsen wrote: ‘*Until now we have had opportunities to see several times how certain strong northern lights haves no magnetic influence whatsoever*’.

The average diurnal and seasonal variations at both stations show great similarities. Maximum occurred near midwinter at both hemispheres. The number of events was nearly double in 1903 compared to 1902 and 1904. Many events moved to zenith and some even further poleward. A large fraction of the observations was associated with very weak magnetic disturbances.

Unique geomagnetic signatures of polar cap aurora were found using data from the expeditions and observations during the space age. The three main types of polar cap aurora were: transpolar arcs (TPA), poleward substorm arcs (PSA) and sun-aligned arcs (SAA). The first two are infrequent polar cap features probably originating in the plasma sheet. These forms seem to be connected with special magnetic signatures and may be mapped even if they are not seen.

On the 14th December 1903, a poleward expansion aurora event was observed at GH, and most probably simultaneous at CA. Similar magnetic effects of poleward expansion of auroras were observed in both hemispheres, near 22hr MLT. Unfortunately, we lack statistical data to prove this finding of similarity at both hemispheres.
SAA occur nearly daily and is probably connected to the geomagnetic solar quiet Sq-variation as is observed at magnetic observatories. The SAA forms appear to emanate from the merging of the interplanetary magnetic field (IMF Bz). The intensity of SAA and the annual, diurnal, and solar cyclical occurrence frequency suggest that they are embedded in "polar rain" and dependent on the density and energy of local photoelectrons. East or west currents are associated with SAA around magnetic noon. According to recent satellite measurements polar cap auroras are caused either by solar electromagnetic radiations, polar rain and/or photoelectrons (cf. Newell et al., 2009).

Acknowledgements

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