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Cosmic Noise Absorption Events and Magnetic Pulsation Activity During Substorms

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Abstract. Meridional profiles of cosmic noise absorption and magnetic pulsations have been analyzed for three substorms observed over Scandinavia during disturbed (December 2, 1977), moderately disturbed (March 1, 1978) and slightly disturbed (March 2, 1978) conditions. Localized absorption events in the afternoon sector, a growth phase of a substorm, breakup phases of substorms and pulsating absorption events are discussed. The activity of Pi2,3 pulsations is enhanced near the position of the polar electrojet and coincides with the location of maximum cosmic noise absorption. Largest pulsation amplitudes occur at times of steeply increasing cosmic noise absorption. Two onsets on December 2 show a similar time delay from south to north in the riometer and the pulsation activity data.

Key words: Cosmic noise absorption CNA – Magnetic pulsations Pi1,2,3 – Polar electrojet – Substorm.

1. Introduction

During a magnetospheric substorm one observed phenomenon is precipitation of electrons into the atmosphere. Auroral absorption events are caused by electrons whose energy is greater than 40 keV.

The initiation of an auroral absorption substorm most frequently occurs near magnetic midnight (The term auroral absorption substorm is used because it is the heavy ionization during the substorm which can be studied by means of riometers in and near the auroral zone). The onset of an auroral absorption substorm in the longitudinal sector where the substorm breaks up is very sharp and a weak equatorwards moving absorption precedes the sharp onset (Ranta, 1978). Latitudinally very localized absorption events (Lukkari et al., 1977) are found at L-values between 3 and 6 in the afternoon sector during a substorm. Absorption events observed at the same time with IPDP type pulsations (Lukkari et al., 1977) are interpreted by Thorne (1974) to be due to drifting protons which are injected towards the earth during the initiation of a substorm and which stimulate instabilities to precipitate energetic electrons from the magnetosphere.

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Some of the electrons injected during a substorm are not precipitated immediately, but are first captured by the closed field lines. In the later phase of a substorm these electrons drift to the morning side and are precipitated there (Arnoldy and Chan, 1969). The longitudinal expansion velocities are in the range 0.7–7 km/s, except for the extreme values which exceed 20 km/s (Berkey et al., 1974). On the morning side well defined absorption pulsations appear occasionally. Absorption pulsations with periods of several minutes and 5–20 s are observed (Hargreaves, 1969).

For magnetic pulsations the onset of a substorm is marked by a Pi2 event (formerly pt) occurring simultaneously at stations in auroral and middle latitudes in the evening sector (Saito et al., 1976). During the expansion phase there is strong activity in the Pi 1,2,3 band preferentially in the vicinity of the auroral zone. These pulsations are assumed to be partly due to hydromagnetic waves in the magnetosphere and to fluctuations of the substorm current systems (Kuwashima, 1975). Theoretical examinations of the magnetospheric origin of magnetic pulsations are developed by Chen and Hasegawa (1974). The propagation of the hydromagnetic waves through the ionosphere down to the ground is treated by Hughes and Southwood (1976a and b).

In this paper the intensity of magnetic pulsation activity for two different period ranges is compared with the occurrence of cosmic noise absorption on a meridional profile in the region of the auroral zone. The data were selected from three different time intervals when several auroral breakups took place over Scandinavia.

2. Measurements

A north-south chain of seven riometers is operated by the Geophysical Observatory in Sodankylä on a routine basis at 27.6 MHz. All riometers use a 3-element Yagi antenna and the region sampled is, at 100 km altitude, about 200 km in east-west extent and about 90 km in north-south extent as shown by the ellipses in Fig. 1. The data are recorded with a chart speed of 60 mm/h allowing 1 min time resolution.

During the IMS (International Magnetospheric Study) the University of Göttingen is operating a meridional chain of 3 component Grenet type induction magnetometers in northern Scandinavia. The data are recorded at a rate of 1 sample/s, and the period range of the instruments extends from 2 s to approximately 600 s, thus covering the range of magnetic pulsations from Pc2 to Pc5 and Pi1 to Pi3. The temporary stations are marked in Fig. 1. The precise locations of the riometers are listed by Untiedt et al. (1978). The geographic and geomagnetic coordinates of the pulsation magnetometers, which are operating at the same sites as the IMS magnetometers of the TU Braunschweig, are given by Maurer and Theile (1978).

3. Results

From the existing data material of the IMS special interval December 1977 and the Auroral Breakup Campaign (ABC) in February/March 1978 three sub-

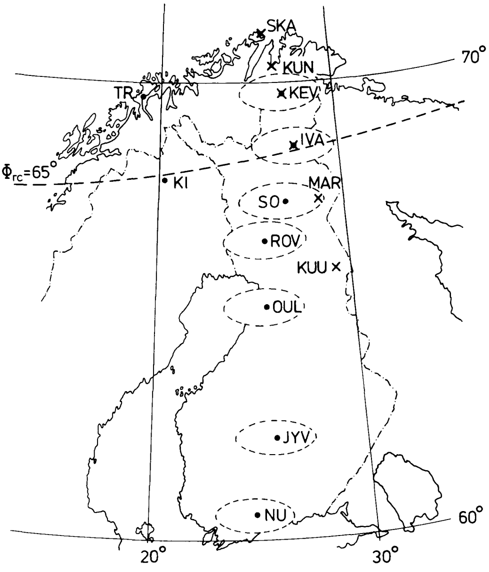

Fig. 1. Map of stations: The seven 27.6 MHz riometers are at *KEV:* Kevo; *IVA:* Ivalo; *SO:* Sodankylä; *ROV:* Rovaniemi; *OUL:* Oulu; *JYV:* Jyväskylä; *NU:* Nurmijärvi. *L*-values of these sites vary between 3.3 and 6.0. Ellipses give the antenna patterns of the riometers projected to the 100 km level in the ionosphere. The locations of the six pulsation magnetometers are *SKA:* Skarsvåg; *KUN:* Kunes; *KEV:* Kevo; *IVA:* Ivalo; *MAR:* Martti; *KUU:* Kuusamo with corresponding *L*-values between 6.8 and 4.6. A curve of constant revised corrected geomagnetic latitude (Gustafsson, 1970), i.e., $\Phi_{rc}=65°$, is denoted by a broken line

storm events have been selected in order to study the possible relation between cosmic noise absorption and magnetic pulsations for times of different magnetic activity:

(a) disturbed conditions on December 2, 1977 (Kp(1200–2400 UT): 4+ 6+ 7o 5−),

(b) moderately disturbed conditions on March 1, 1978 (Kp(1200–2400 UT): 5− 5o 5+ 5o),

(c) slightly disturbed conditions on March 2, 1978 (Kp(1200–2400 UT): 3+ 3o 4+ 3o).

Cosmic noise absorption measurements are analyzed with special emphasis on the events seen in the afternoon sector and around magnetic midnight. For all stations the local magnetic time is about UT+3 h.

The magnetic pulsation data were treated by dynamic spectral analysis with an output of 60 period bands between 5 and 300 s. In this paper the results are compressed into two bands 'Pi1' (5 to 40 s) and 'Pi2,3' (45 to 300 s) with one intensity value every four minutes giving the maximum of the peak to peak amplitude during this time interval. This procedure takes into account the different behaviour of Pi1 and Pi2 pulsations and the maximum time resolution of the method.

3.1. Event of December 2, 1977

There is strong pulsation activity during the whole day. In Fig. 2 riometer and pulsation data of December 2, 1977, 1600–2300 UT are displayed. The magnetic pulsation activity in the 'Pi2,3' band estimated by the spectral analysis described above is shown in a contour map of the total horizontal component $(T=\sqrt{H^2+D^2})$ in a time versus latitude display. For the 'Pi1' band the analogous contour map contains similar results.

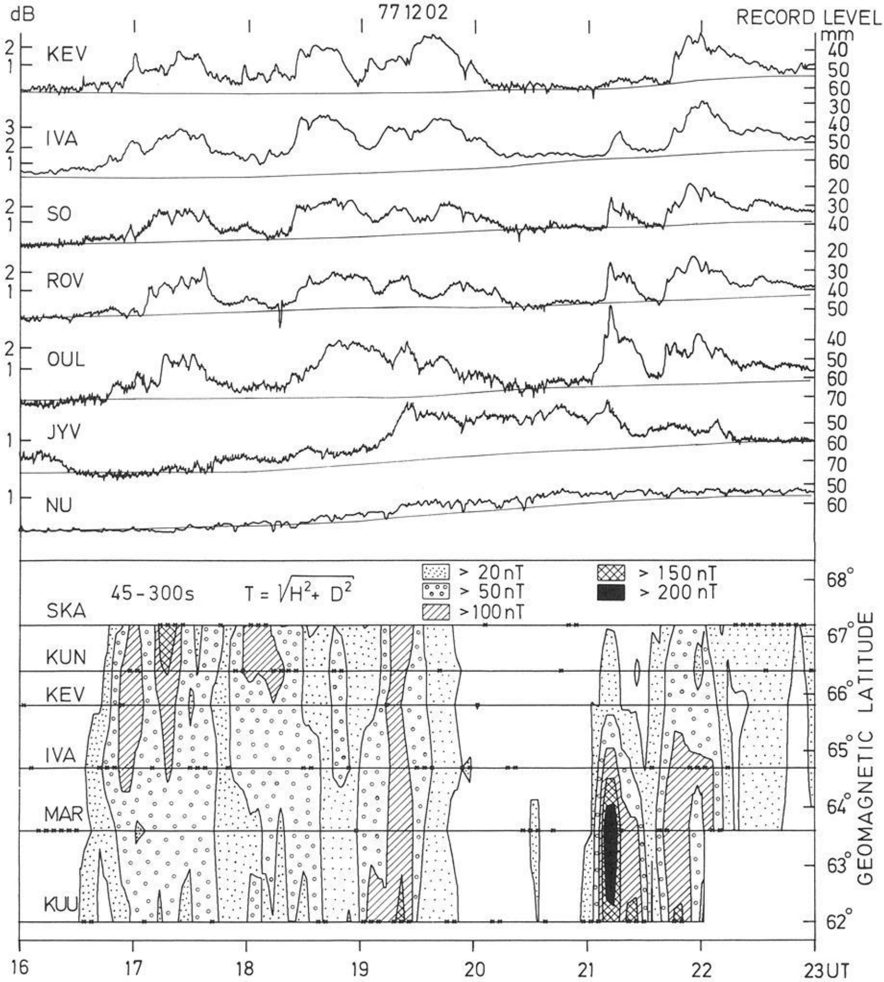

Fig. 2. Cosmic noise absorption recorded by the Finnish riometer chain and data of the Göttingen pulsation magnetometer chain for December 2, 1977, 1600–2300 UT. *Upper panel:* Riometer recordings, undisturbed levels are indicated. *Lower panel:* Magnetic pulsations presented by contour lines of equal amplitude vs. time and geomagnetic latitude for the total horizontal component. The contour lines (20/50/100/150/200 *nT*) indicate the double amplitude envelope of the 'Pi2,3' band (45–300 s). Every four minutes the station with maximum amplitude is marked. No data of *KUU* exist after 2200 UT

Between 1630 and 2000 UT pulsating absorption is observed north of OUL, i.e., the absorption level varies with periods of approximately 5–10 min. No sharp onset is seen during these hours indicating that observed substorms do not break up above Finland but west of it. Pulsating absorption appears most clearly at ROV. The maxima occur at 1708, 1715, 1724, 1730, and 1736 UT.

The magnetic pulsation activity on average increases after 1645 UT, approximately, with a maximum at 1659 UT at KEV. In the original data a time delay in the maximum of activity between the southern and northern stations can be recognized (2 min in the *H*-components of MAR and KUN). At this time the IMS magnetometer chains of Braunschweig and Münster observe a westward electrojet in northern Scandinavia.

Around 1718 UT, predominantly the northern stations from IVA to SKA record a second Pi2. Simultaneously the *H*-component of the magnetic field increases, especially at KEV and KUN. Near 1800 UT another maximum of activity is observed in the north with two distinct maxima in the original data of KEV, KUN, and SKA at 1756 and 1812 UT respectively. They coincide with increasing absorption at KEV.

In contrast to the previous events the maximum of 'Pi2,3' amplitudes around 1920 UT is found in the south. A detailed analysis reveals increasing *H* and decreasing *D* amplitudes from south to north. The displacement of the general pulsation activity to the south is accompanied by a southward movement of the minimum of *H* in the standard magnetograms, i.e., the westward polar electrojet is shifting to the south.

After 2020 UT only small absorption is seen at JYV. Two clear breakups happen after 2100 UT. Between 2103 and 2110 UT a small absorption event can be recognized at OUL and JYV. Then, the first onset starts at these two stations. Later, at 2112 UT it occurs at IVA. At KEV this substorm cannot be observed clearly. The second onset which starts at 2141 UT at OUL, begins later in the north, at 2145 UT at KEV. After 2200 UT the absorption decreases smoothly. Also during these substorms some pulsating absorption is observed. At ROV, for example, the maxima are seen at 2113, 2120, 2123, 2143, 2148, 2158, 2204, 2208, and 2222 UT, with a distinct minimum between 2130 and 2141 UT.

Simultaneous with the first absorption onset and auroral breakup an increase of the magnetic pulsation amplitudes and of the westward electrojet occurs at 2110 UT in the south. The modulation of the absorption signal described before can also be detected in the magnetic pulsation activity, but because of the resolution of 4 min, however, only four distinct maxima at the southern pulsation stations are seen, at 2113, 2123, 2148, and 2204 UT. The time delays of the absorption onsets for station pairs OUL – IVA and OUL – KEV mentioned above can also be seen in the intensity level of the original magnetic pulsations. Nevertheless the Pi2 onsets at 2110 UT and 2141 UT occur simultaneously at all stations (with small amplitudes in the north). For the second onset the time shift from south to north is obvious too in the negative slope of the *H*-component of the IMS magnetometers between IVA and SKA. Around 2200 UT the region of maximum 'Pi2,3' activity starts migrating to the north with slowly decreasing amplitudes. This is coincident with a northward movement and decrease of the westward polar electrojet.

3.2. Event March 1, 1978

During the Auroral Breakup Campaign (ABC) in February/March 1978 only the two pulsation stations KEV and MAR were operating. In Fig. 3 the original

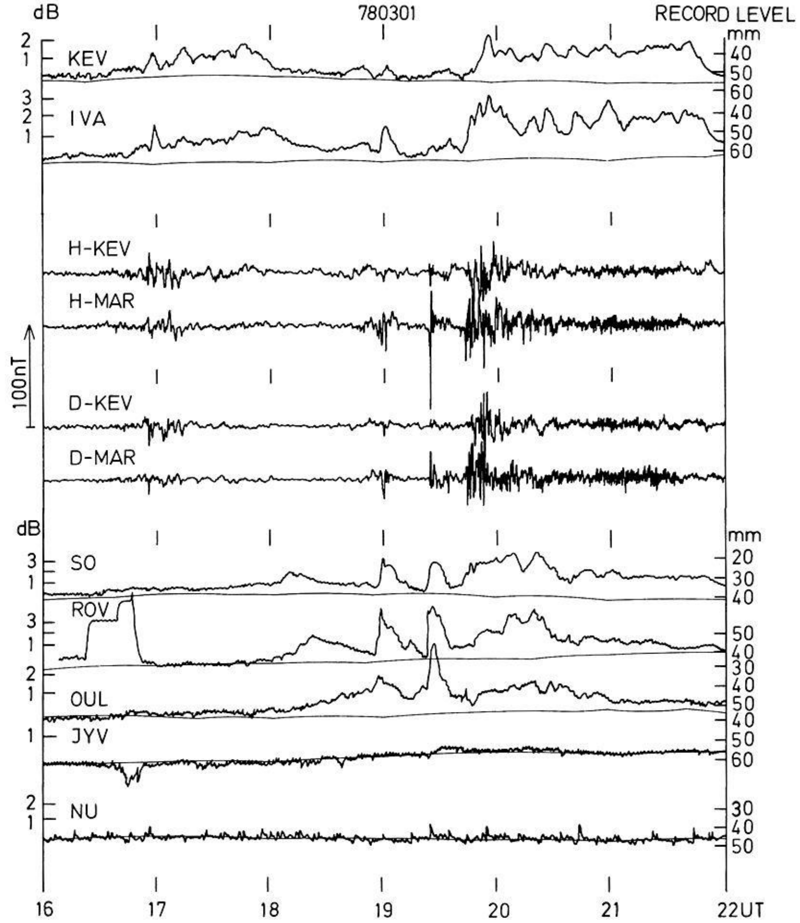

Fig. 3. Riometer and pulsation recordings for March 1, 1978, 1600–2200 UT. To facilitate the comparison the pulsation data of the horizontal components of *KEV* and *MAR* have been inserted in the northern riometer stations. The indicated scale value of 100 *nT* exactly belongs to a period of 20 s

data of the *H*- and *D*-component of both stations are shown together with the riometer data for March 1, 1600–2200 UT.

From 1635 to 1850 UT some absorption is seen at IVA and KEV with a peak around 1657 UT. The sharp onset of a substorm occurs at ROV at 1856 UT and at IVA at 1859 UT. At OUL the absorption begins at about 1855 UT, at KEV at about 1900 UT. A small absorption event preceding the onset is seen north of OUL; it propagates equatorwards. The intensification factor and the propagation speed can be evaluated by comparing the absorption values of SO and ROV. In this event the factor is 1.2 and the speed 130 m/s.

Another onset with preceding absorption is seen at OUL, ROV, and SO at 1924 UT. But the riometers at IVA and KEV do not show this sharp onset. The small preceding absorption is disturbed by the previous substorm. Therefore this equatorwards moving absorption can only be distinguished at OUL and ROV.

After these two onsets pulsating auroral absorption is observed between 1940 and 2200 UT. The pulsation of electron precipitation is best seen at IVA. At first the period is about 4 min with maxima at 1948, 1952, and 1957 UT. After 2000 UT the period of pulsating absorption varies between 10 and 20 min (maxima at 2004, 2022, 2028, 2044, 2101, 2120, 2133, and 2143 UT). From 2200 to 2300 UT the absorption is rather small, and it begins to increase smoothly after 2300 UT.

Strong magnetic pulsation activity starts at 1654 UT with larger amplitudes at KEV, coinciding with absorption peaks at KEV and IVA. The equatorward travelling absorption between 1800 and 1900 UT is not accompanied by any significant magnetic pulsation structure.

During the first absorption onset the magnetic pulsation activity increases at 1856 UT and reaches a maximum around 1859 UT at MAR. The second onset at 1924 UT is accompanied by a very distinct Pi2 event at MAR, coinciding with the maximum of ionospheric absorption at SO, ROV, and OUL. This Pi2 shows much smaller amplitudes at KEV. Between both onsets the magnetometer chain observes a southward moving eastward electrojet; after the second onset a westward electrojet appears around IVA. The fine structure of the absorption at IVA cannot distinctly be seen at both pulsation stations. MAR, however, has maxima of intensity at 1949 UT and 1959 UT.

The interval from 2000 to 2200 UT shows short period storm associated pulsations, especially at MAR, while long period pulsations of comparable amplitude occur at both stations. The general position of the westward electrojet as derived from the magnetometer data is predominantly in the south, between IVA and MAR.

3.3. Event March 2/3, 1978

In Fig. 4 the pulsation and riometer data of this slightly disturbed event are shown for the time interval 1800 to 0100 UT. From 1800 to 2100 UT small absorption is observed north of ROV. At 1800 UT a series of Pi2 events starts with larger amplitudes at KEV. Simultaneously an eastward electrojet is centered over KEV moving equatorwards. The absorption peak at KEV at about 2016 UT coincides with an auroral arc and high Pi2 activity at this station. The records of the IMS magnetometer chains show the pattern of a Harang discontinuity for this time. Hereafter the activity decreases slowly.

At 2223 UT an absorption onset occurs simultaneously at SO and KI (Kiruna) which is only visible at stations north of OUL. The extremly sharp onset at KI indicates that the auroral breakup happens quite near KI. It is accompanied by strong pulsation activity starting with a Pi2. Worth noting are the different patterns of the pulsation records from KEV and MAR; the larger amplitudes prevail at MAR and at the onset the Pi2 in the *H*-component shows nearly opposite phase behaviour. During this event the existing westward electrojet suddenly moves from IVA to MAR and returns to IVA at about

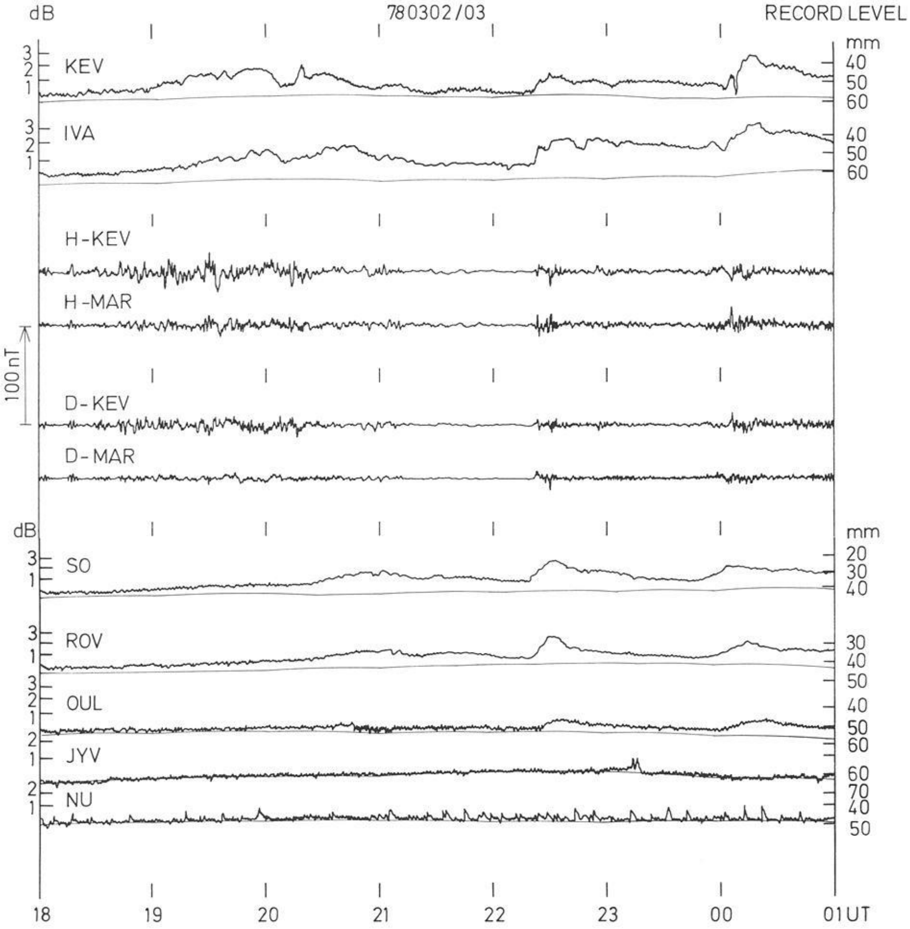

Fig. 4. The same as Fig. 3 for the event March 2/3, 1978, 1800–0100 UT

2250 UT. A further Pi2 onset at 2230 UT behaves in the same manner as far as the phase of *H* is concerned. This event is correlated with a sharp increase of absorption at IVA. At this time two auroral arcs are observed, one north of KEV and a weaker one south of MAR.

The activity decreases after 2300 UT and starts again shortly before 0000 UT, lasting up to about 0300 UT. Between 0000 and 0300 UT slowly varying absorption is seen north of OUL. Maxima are found at IVA at 2358, 0023, 0110, and 0122 UT, at ROV at 0017 and 0113 UT.

4. Discussion

In the preceding chapter the behaviour of magnetic pulsation activity and of the absorption of cosmic noise for three different disturbed intervals has been described. Generally a rising CNA (cosmic noise absorption) is coupled with an intensification of Pi activity in both studied period bands (from 5 to 300 s). In detail the largest amplitudes of these pulsations occur just after the onset of absorption events and sometimes remain for the time of maximum absorption. The absolute level of CNA is not coupled to the degree of pulsation activity. However, during each substorm event maximum CNA and maximum pulsation activity occur at the same region of the meridional profile. This is in agreement with results of Novikov et al. (1979), which, different from this investigation, were found for the plasmapause region.

In the event of preceding absorption during March 1 the magnetic pulsations do not show any significant alteration. When the magnetosphere is considered to be the only source of pulsation activity this observation means that there is an influence neither on the generation process of the magnetic pulsations nor on the transmission qualities of the ionosphere during the time of preceding absorption.

According to Wilhelm et al. (1977) the magnetic pulsations in the auroral latitudes are composed of oscillations of magnetospheric origin and irregular fluctuations of ionospheric currents (mainly polar electrojet) and Birkeland currents. Saito et al. (1976) identify substorm onsets by low latitude Pi2. All absorption onsets described in Sect. 3 fall together with clear Pi2 events at the midlatitude station Göttingen. The amplitudes of these Pi2 reach their maximum at auroral latitudes (Baranskiy et al., 1974). This explains the strong pulsation activity just after the onset. The event with the most pronounced Pi2 amplitudes at the onset occurred on March 1 at 1924 UT (see Fig. 3). At this time the auroral breakup happened to be just over the profile. It is coupled to an impulsive Pi2 event in the H-component at MAR, the station closest to the breakup.

The time delays between southern and northern stations on the meridional profile during December 2, 1977, around 2112 and 2145 UT, are recognizable in the absorption and the magnetic pulsation intensity data thus giving an apparent south-north velocity of roughly 2–3 km/s. The magnetograms just indicate the second time delay because only the four northern stations were operating at this time and the first event occurred too far south. The pulsation event around 1658 UT gives a similar poleward velocity. The same observation of poleward travelling Pi2 intensity together with a parallel movement of the electrojet was made by Olson and Rostoker (1975). In contrast to their result the Pi2 onsets (December 2 event) occurred simultaneously at stations from midlatitudes to far north of the electrojet; however, the amplitudes of the Pi2 at the onset times are very small in the north. The velocity mentioned above agrees with the speeds of plasma drift motions in the vicinity of active auroral arcs (Whalen et al., 1975).

The clear events of pulsating CNA are correlated to variations found in the standard magnetograms of the corresponding stations. Especially the riometer data and the records of the magnetic H-component show similar behaviour. The sensitivity of the pulsation instruments for this period range (about 400 s) is low, so these events are masked by shorter period activity. On the other hand the time resolution of the riometer is not good enough to allow a detailed comparison with magnetic pulsations of periods lower than 300 s. However the

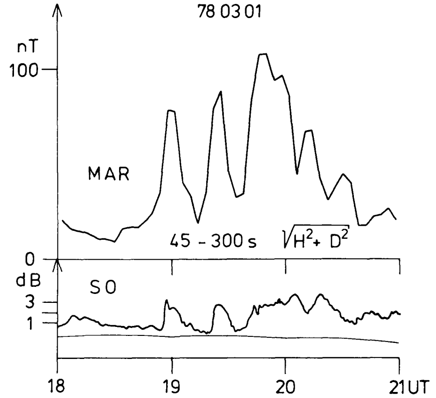

Fig. 5. Display of the pulsation activity at *MAR* and the cosmic noise absorption at *SO* for March 1, 1978, 1800–2100 UT. The maximum double amplitude of the total horizontal component of *MAR* taken every four minutes is plotted

pulsation activity and the CNA usually show a parallel development. For a 3-h interval Fig. 5 demonstrates this correlation. It displays the riometer record of SO and the magnetic pulsation activity in the 'Pi2,3' band at MAR which is situated about 80 km east of SO. At the beginning both curves show an identical behaviour. During the main phase of the substorm (after 2000 UT) the general features of the two plots are similar, but it is difficult to relate single absorption peaks to pulsation activity peaks. Hargreaves (1974) distinguishes between two classes of absorption peaks, those occurring within 10 min of the onset and those 30 min after substorm beginning.

A direct comparison between the magnetic pulsation periods and the riometer data was not possible. According to Stuart et al. (1977) the modulation of the intensity of precipitating electrons in the auroral zone is correlated to coincident Pi2's. After Heacock and Hunsucker (1977), using a high time resolution riometer at College, Alaska, Pi1,2 magnetic pulsations are highly correlated with the pulsating component of the riometer data. Therefore the dominant periods of magnetic pulsations should also be present in the CNA.

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