Pc 1-2 and IPDP pulsations

Introduction

Continuous geomagnetic ULF waves with period of **0.2 - 10 s** are called Pc 1-2 pulsations (a special subclass has been termed IPDP). Pulsations at these frequencies are generated by the electromagnetic ion cyclotron (EMIC) instability near the magnetic equator, and they are thus called **ion cyclotron waves**. There are three observational facts supporting the EMIC nature of the waves:

1. electromagnetic nature of the waves
2. predominance of left-hand polarization near the equator
3. existense of a gap in spectral power in the vicinity of the helium gyrofrequency, F(He+)

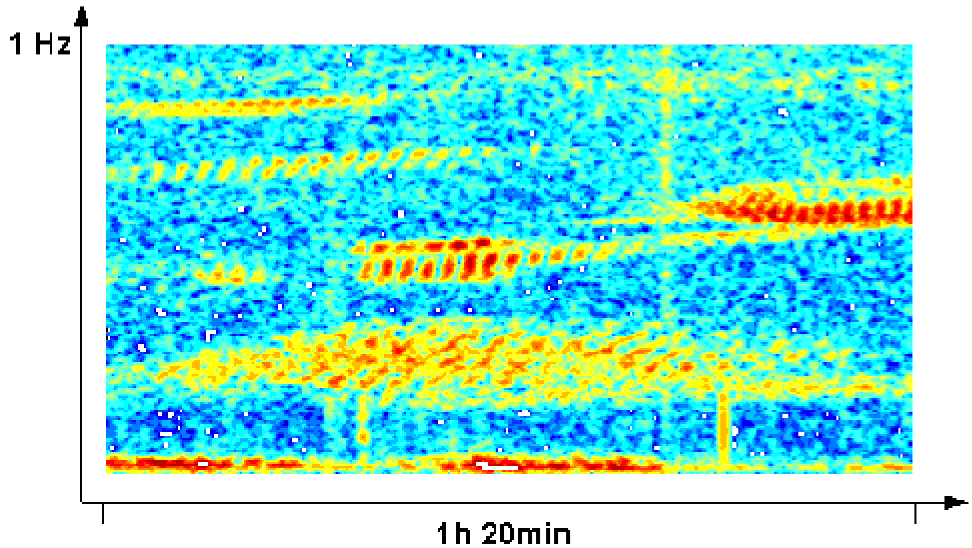

Figure: Ground based observations of structured Pc 1 pulsations.

Pc 1-2 waves propagate towards the ionosphere along the field line, and can be observed also on the ground, as reported already by Sucksdorff (1936) and Harang (1936). Two main subgroups have been identified on basis of ground observations: structured pulsations (also known as periodic or pearl pulsations) and unstructured pulsations (Fukunishi et al., 1981).

Energy for the EMIC wave generation is provided by temperature anisotropies (Tperp > Tpar) of magnetospheric protons in the energy range 10 - 100 keV. For example, solar wind compressions of the magnetosphere favour Pc 1 generation, as the compressions increase the ion anisotropy which, in turn, increase the wave growth rate (Olson and Lee, 1983; Kangas et al., 1986). The necessary ions can be either of ring current (mid- and low-latitude events) or plasma sheet (high-latitude events) origin.

Occurrence distribution

The effective amplification of EMIC waves depends on the amount of time spent propagating through a finite growth region (Kozyra et al., 1984), and the convective growth rate is thus inversely related to the group velocity of the waves. Since the group velocity is related to the Alfvén velocity Va, enhanced cold plasma densities and low magnetic field strengths (= low Va) favour the wave growth. Since the magnetic field lines have minimums at the equator, the wave growth occurs there. A minimum in Va occurs typically just inside the plasmapause (maximum *at* the plasmapause; e.g., Fraser et al., 1992) and, accordingly, two types of Pc 1-2 pulsations are related to this region close to the ring current: the so-called structured or pearl Pc 1 pulsations (see, e.g., Erlandson et al., 1992) and the IPDP events. The ring current ion source depends strongly on geomagnetic activity, and the pearl events occur typically during a recovery phase of a geomagnetic storm, while the IPDPs occur during the active phase of a substorm. The structured pulsations are most often seen in the morning sector (Saito, 1969).

However, the plasmapause is not the most important region for EMIC wave growth. Observations from both magnetosphere (Anderson et al., 1992a) and ground (Plyasova-Bakounina et al., 1996) show maximum Pc 1-2 occurrence probability at L=7-9, ML=12-15, indicating that the **plas ma sheet ions are the most important energy source** for the waves. A weaker maximum is found in the dawn sector (03-09 MLT). These high latitude pulsations are unstructured (e.g., hydromagnetic chorus type), and storm independent. However, the emissions may be modulated by Pc 4and Pc 5 pulsations (e.g., Plyasova-Bakounina et al., 1996).

Finally, some very high latitude (ground based) events observed in the dawn sector have been explained by ions injected in the cusp/cleft region, and drifting westward towards dawn (Hansen et al., 1992). However, it is possible that these are solar wind controlled pulsations leaking into the magnetosphere through the cusp (Plyasova-Bakounina et al., 1996), or waves related to plasma mantle (Dyrud et al., 1997).

Satellite observations have shown that the latitudinal extent of Pc 1 wave events are of the order of 100 km when projected into the ionosphere (Iyemori and Hayashi, 1989; Erlandson *et al.*, 1990; Erlandson and Anderson, 1996). Individual bursts have even smaller extent. The events are much more extended longitudinally, as the ions providing the energy drift around the Earth.

Structured (pearl) pulsations

The pearl pulsations appear as repetitive bursts of Pc 1 waves, formed by wave packets propagating along magnetic field lines between conjugate points and partially reflecting from the ionosphere. Accordingly, it has been shown that the bursts are in antiphase in the northern and southern hemispheres. The figure here shows a Pc 1 pearl (electric field component) as observed in the ionosphere by the Freja satellite (Mursula et al., 1994). For the wave growth to occur, the reflected wave's k-vector should be parallel to **B**, and this is possible only in the presence of a density gradient. Such a gradient occurs at the plasmapause and, indeed, all structured events have been found to occur just inside or near the plasmapause. Note, however, that the validity of the wave packet theory has lately been questioned (e.g., Mursula et al., 1997).

The pearl events exhibit a positive frequency-time dispersion which is of the order of 50 s/Hz. The dispersion is most likely formed already in the magnetospheric source region, as suggested by the theoretical work by Gendrin et al. (1971), and by the satellite observations from Freja (Mursula et al., 1994) and Viking (Erlandson et al., 1996).

It has been suggested that the EMIC emissions can be structured also without the density gradient simply via modulation by lower frequncy waves (Pc 4-5 range; see, e.g., Plyasova-Bakounina et al., 1996; Rasinkangas and Mursula, 1998). This may be an important factor at least in the outer magnetosphere. In addition, the possibility that ionospheric Alfvén resonator may be able to create pearl structures has been suggested.

Wave properties

The EMIC waves grow typically at frequencies 0.1 to 0.5 times the equatorial proton gyrofrequncy, F(H+). In the first approximation, the most significant amplification of EMIC waves should occur below the equatorial helium gyrofrequency, F(He+) = 0.25×F(H+). Since gyrofrequncies depend on magnetic field strength (qB/m), one would expect decreasing wave frequencies at higher latitudes. This is also often observed. However, the Viking observations (Erlandson *et al.*, 1990) have shown that while at lower invariant latitudes (59°-72°) EMIC waves do occur at f < F(He+), at higher invariant latitudes (70°-77°) they are seen above this frequency (note that no waves can grow close to F(He+)). This fact was explained by the linear wave growth rate dependence on the heavy ion energy and anisotropy, and partly also by wave propagation characteristics (ray tracing studies have shown that waves below F(He+) are well guided, while those above are not). It is actually the latter type of waves that are more typical.

To investigate further the frequency properties, we introduce a normalized frequency X = F/F(H+), where F is the local, observed wave frequency, and F(H+) is the equatorial proton gyrofrequency along the same field line. This value is always < 1 and, for waves F < F(He+), X < 0.25. Waves with X < 0.25 and 0.25 < X < 0.45 are typically seen at the early afternoon occurrence maxima, while waves with higher X are seen within the dawn sector (03-09 MLT) secondary peak. Even more striking difference concerns the **polarization** characteristics of these populations: the dawnside events seem to be generated with polarizations ranging from purely left-hand to linear, while the afternoon side events are of the typical left-hand type (Anderson et al., 1992b). It is not possible to explain this feature in terms of crossover from left- to right-hand polarization occurring typically during propagation from low to high magnetic field strengths (towards ionosphere).

Ionospheric effects

Comparison of the Pc 1 waves observed in space and on ground is not always straightforward, since the field line guidance of Pc 1 waves stops in the ionosphere, and ground-based observations are influenced by ducting of waves in the ionospheric waveguide (e.g., Fujita, 1987). The ducting has an interesting side-effect, called multiband Pc 1 events, where observed on the ground sees emissions at two or more frequency range simultaneously. They are formed as emissions from different source regions (L-shells) are ducted within the ionosphere to a point on the ground. Note that this is different than having band-like structure because of the splitting of the emission spectra by magnetospheric heavy ions (He+ and O+). Furthermore, there are some evidence of rare occurrence of multiband structured pulsations produced solely within one source (Feygin et al., 1994).

IPDP pulsations

IPDP (intervals of pulsations of diminishing periods) tend to occur during the active phase of geomagnetic substorms in the afternoon-evening sector (Hayakawa et al., 1992).

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