

Dayside Pc5 pulsation detected by Viking ion data at L=4.

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Abstract. On September 12, 1986, when the largest magnetic storm ($Dst = -157$ nT) during Viking operations took place, the satellite observed unusual energy modulation of sub-keV ring current ions. The modulation is seen in both the pitch angle domain (conic-like distribution) and the space-time domain (wavy variation of ion flux with a period of a few minutes). The wavy variation is synchronized with a clear and distinct magnetic field-line oscillation which is probably a standing Alfvén wave. This is observed simultaneously on the ground as a Pc5 pulsation over a wider range of latitude than the satellite observation.

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1. Introduction

While so-called CPS and BPS (as of defined by low-altitude observations) have been studied by many researchers for both keV and hundred eV ranges [Winningham *et al.*, 1985; Newell *et al.*, 1992; Woch and Lundin, 1993, and references therein], sub-keV (< 300 eV) trapped ions ("low-energy ring current ions" [Collin *et al.*, 1993]) equatorward of CPS are not well investigated. Many studies near or inside the plasmasphere have been focused on energetic (> keV) or thermal (< 10 eV) ions, but not on low-energy (< 300 eV) ions either at high-altitude [e.g., Lennartsson and Sharp, 1982] or low-altitude [e.g., Hultqvist, 1979]. The sub-keV trapped ions in this region are often considered as a mere low-energy extension of the radiation belt.

Using DMSP data, Newell and Meng [1986] studied sub-keV (down to 30 eV) ions down to $L \approx 2.5$, and found an isolated region of sub-keV plasma sheet like ion precipitation within the plasmasphere in the early morning sector (postmidnight to 0830 MLT). Indications of this "isolated plasma sheet" are reported also in Shelley *et al.* [1972], Sauvaud *et al.* [1981], and in Chappel *et al.* [1982] with different terminology.

Using CRRES (apogee 6.3 Re) data, Collin *et al.* [1993] independently showed that sub-keV ring current ions are clearly separated from the ordinary (> 5 keV) ring current ions in the energy domain. The threshold energy is around 3 keV at any latitude, local time, and pitch angle. Viking observations confirm this separation [Yamauchi *et al.*, 1995]. The sub-keV trapped ions equatorward of CPS exist over the entire dayside, and sometimes overlaps with CPS or with the plasmasphere, and is sometimes completely separated from them. The region has internal meso-scale structures of a few degrees wide each. The occurrence, location and internal structure of this region are very variable in space and time [Yamauchi *et al.*, 1996]. Certainly, the sub-keV "ring current" is a different plasma region from the ordinary ring current.

The relationship between the "isolated plasma sheet" and this region is unclear. Yet, it is worth giving a new name to this sub-CPS region (of sub-keV "ring current" ions as of Viking and CRRES observations) in order to avoid confusion. We temporarily call it the "DPS," a simple alphabetical extension from BPS and CPS. We believe this name is more neutral and specific than "ring current." The overall DPS features, especially the internal structure will be reported in a different paper. We here present one striking example of the DPS internal structure during a major magnetic storm.

2. September 12, 1986 Event

In Viking data, DPS is observed as an ion signature and is not recognized in the electron spectrogram. This is probably because of the much better sensitivity for ions than for electrons in low-energy (< 300 eV) regimes. Plate 1 shows a Viking observation of DPS on September 12, 1986 (orbit number #1114) during the largest magnetic storm ($Dst = -157$ nT) in the Viking data taking period. The Dst index is shown in Figure 1. In the ion spectrogram, a distinct region of low-energy (< 3 keV) ions is seen at 0806-0842 UT (55° - 62° INV). This is the "DPS." It is spatially separated from both the ordinary CPS (appears after 0848 UT) and the ordinary (> 3 keV) radiation belt. The poleward boundary of DPS in this orbit happens to be located at the plasmopause, but this is a mere coincidence. According to Viking (about 400 DPS observations), DPS is almost always extended far poleward of the plasmopause. The ion flux is even more intense at the DPS than at the stagnant plasma injection (SPI) [Yamauchi *et al.*, 1993] which is seen at 0854-0857 UT (65° INV). This is one of the strongest DPS among all Viking data. Yet we are unable to recognize any specific electron signature within the energy range of 50 eV-40 keV (Plate 1 shows only 3-40 keV) except very uniform trapped electrons. Viking detected clear DPS in orbits #1114 and #1115 but not in orbit #1113 during the main phase of the storm (cf. Figure 1). Compared to all the other Viking data, the sub-keV ion counts in #1113 are surprisingly low as if some vacuuming mechanism is present. In the orbit #1114 we see more intense and more structured DPS than in orbit #1115. The DPS is thus very variable in time and space. In this paper, we report a unique observation of a wavy feature among many internal structures.

2.1. Field Observation

One can easily recognize a modulation of the characteristic energy in the sub-keV ion data at the poleward part of the DPS (0832-0843 UT). The modulation period is a few minutes (160-180 sec). This wavy structure is synchronised with a large-amplitude oscillation of the magnetic field, the electric field, and the plasma drift. The plasma pressure is constant during this oscillation and the oscillation of the magnetic field is only in the east-west direction, both suggesting that it is an azimuthal (east-west)

oscillation of the geomagnetic field lines; i.e., the standing Alfvén wave. In the frozen-in approximation, a northward electric field (ΔE_{north}) means a westward convection in the northern hemisphere, and it must lead an eastward magnetic field (ΔB_{east}) by 90 degree phase angle for a non-compressional oscillation. The observation agrees exactly with this expectation. The Alfvén velocity calculated from the E/B ratio ($\Delta E \approx 20$ mV/m and $\Delta B \approx 30$ nT) is about 700 km/s. Multiplied by the half-period (80 sec), we obtain a local value of half-wave length ≈ 9 Re. Since Viking altitude is about half-way between the ionosphere and the equator on the same field line, this value (9 Re) is a good estimate of the eventual wave length this oscillation although the Alfvén velocity heavily depends on altitude. The result is consistent with the basic mode ($n=1$) oscillation.

A standing Alfvén wave should be detected as a Pc5 pulsation on the ground. Viking was fortunately traversing over the EISCAT magnetometer chain over Finland shown in Figure 2, which shows a giant Pc5 pulsation as is summarized below:

1. The giant Pc5 pulsation is observed during an entire hour at the ground. Therefore, the start and end times of the pulsation detected by Viking imply the equatorward and poleward limits of the oscillating L-cells.

2. The ground Pc5 pulsation is observed over a much wider latitudinal extent than the Viking observation. Kiruna (east of the Finland chain; not listed here) also detected the same pulsation. Thus many ground stations located outside the oscillating L-cell (as of Viking observation) observed the Pc5 pulsation. Certainly, it is difficult to know the location of the oscillating L-cell just from the ground pulsation.

3. The phase of the oscillation at NUR ($L=3.5$) leads those at the northern ($L > 5$) stations, and the time lag between PEL ($L=5.1$) and NUR is very small. Therefore, the oscillation at around $L=4$ must lead the entire ground Pc5. The phase velocity is read $\approx 3^\circ\text{-}4^\circ/\text{min}$ (or 6-7 km/s) poleward, and the latitudinal wave length is read as $> 8^\circ$ which is much longer than the extent of the region where Viking detected the wave.

4. The wave form is strongly modified toward the north. At around 0835 UT when Viking traversed over the Finland magnetometer chain, for example, the shortest periodicity ($T = 160$ sec which is the same periodicity that Viking detected) is seen only at the southernmost stations (NUR, PEL and MUO). This basic mode is not seen at the northern stations.

The observation indicates that the global magnetic field oscillation, which is confined within a limited latitudinal range at around $L=4$ close to NUR, is converted to another

(unknown) mode which can propagate perpendicular to the geomagnetic field, and that the converted wave does not leak beyond the ionosphere. The Pc5 pulsation outside the oscillating L-cell must be generated locally inside or below the ionosphere. This explains the strong modification of the wave form of the ground Pc5 even at a short distance from the source. The ground Pc5 pulsation is a summation of the source oscillation and the converted wave. It also explains why the wave form at ground (even at PEL and NUR) is not as distinct as that seen by the satellite. Then, the question is what is the mode of the converted (propagating) wave.

Geomagnetic disturbances such as PRI propagate very fast (within few minutes between the pole and the equator) along the "wave guide" of the non-conducting atmosphere sandwiched by the ionosphere and the ground [e.g., *Araki*, 1977]. This could be one possibility. However, we have a problem in the propagation speed: the phase velocity (which is probably the group velocity) of the observed ground Pc5 is very slow (only 6-7 km/s). The problem is left for the future.

2.2. Particle Observations

The most peculiar feature of this pulsation is the field-aligned ion acceleration which is synchronized with the pulsation. The temperature oscillation, which is not predicted for an ideal MHD Alfvén wave, is caused by the energy modulation of such field-aligned ions. The energy modulation is detected only for ions but not for electrons.

Since a standing Alfvén wave may produce a finite field-aligned potential drop as a non-perfect MHD effect [e.g., *Lysak*, 1991], the observed energy modulation might be attributed to the modulation of parallel potential drop. In fact, we see more trapped ions above the "acceleration" energy than below it, supporting this scenario. However, the statistics do not support it. We surveyed all Viking orbits and found many examples of electromagnetic oscillations inside DPS, but the energy modulations of these cases are seen only in trapped ions, and are never seen in the parallel component. The present case is just exceptional, and we cannot answer why the parallel potential acceleration scenario does not work for the other "wavy" cases. Another problem is the coexistence of downward ions at the same energy as upward ions. They are less intense than upward ions, but they do exist. Furthermore, field-aligned ion beams with a loss cone are seen even at the equatorward of the oscillation (appears from 56° INV). All these

features are not easily explained by the field-aligned potential drop and the mirror mechanism.

Another possible explanation is perpendicular heating [e.g., *André*, 1990] because the ion structure looks more like conics than beams. However, their appearance is quite different from the ordinary conics observed by Viking. Also, the low-frequency waves are not enhanced during this period until 0845 UT. If ever the ion structure is caused by the perpendicular heating, the heating mechanism must be quite different from the ordinary ion heating.

2.3. Wave Formation Mechanism

Since this is an exceptional event (the wave amplitude is exceptionally large at L=4 in dayside and the particle behavior is something what has never been observed before), it is difficult to address the generation mechanism of this giant pulsation. A general explanation for the standing wave formation mechanism may not apply. One possible candidate that may contribute to the wave formation is the dense plasma of the DPS. Since a plasma density gradient may cause instability, this is not unrealistic. In fact, the pulsation is found exactly at the poleward edge of the DPS in the present case. However, this does not explain many other intense DPS observations by Viking without waves and with waves in the middle of DPS. Another scenario is that the wave and DPS exist independently, and that the pre-existing wave made the DPS wavy. Only when both the field oscillation and the DPS density gradient exceed a certain value at the right position, might the positive feed back begin to take place (i.e., not as a linear instability). This does not explain the cause of the wave at all, but yet explains the peculiarity of the present observation.

3. Summary and Conclusion

Low-energy (sub-keV) ring current ions, which we denote "DPS" ions, contain many different meso-scale (a few degrees each) internal structures. Among those, we examined the wavy structure of particle characteristic energy synchronized with Pc5 type electromagnetic pulsation during a major magnetic storm. This is a unique observation of the ion energy modulation in the field-aligned direction. The oscillation can be understood as a standing Alfvén wave, but the behaviour of these ions is beyond our understanding and needs further study.

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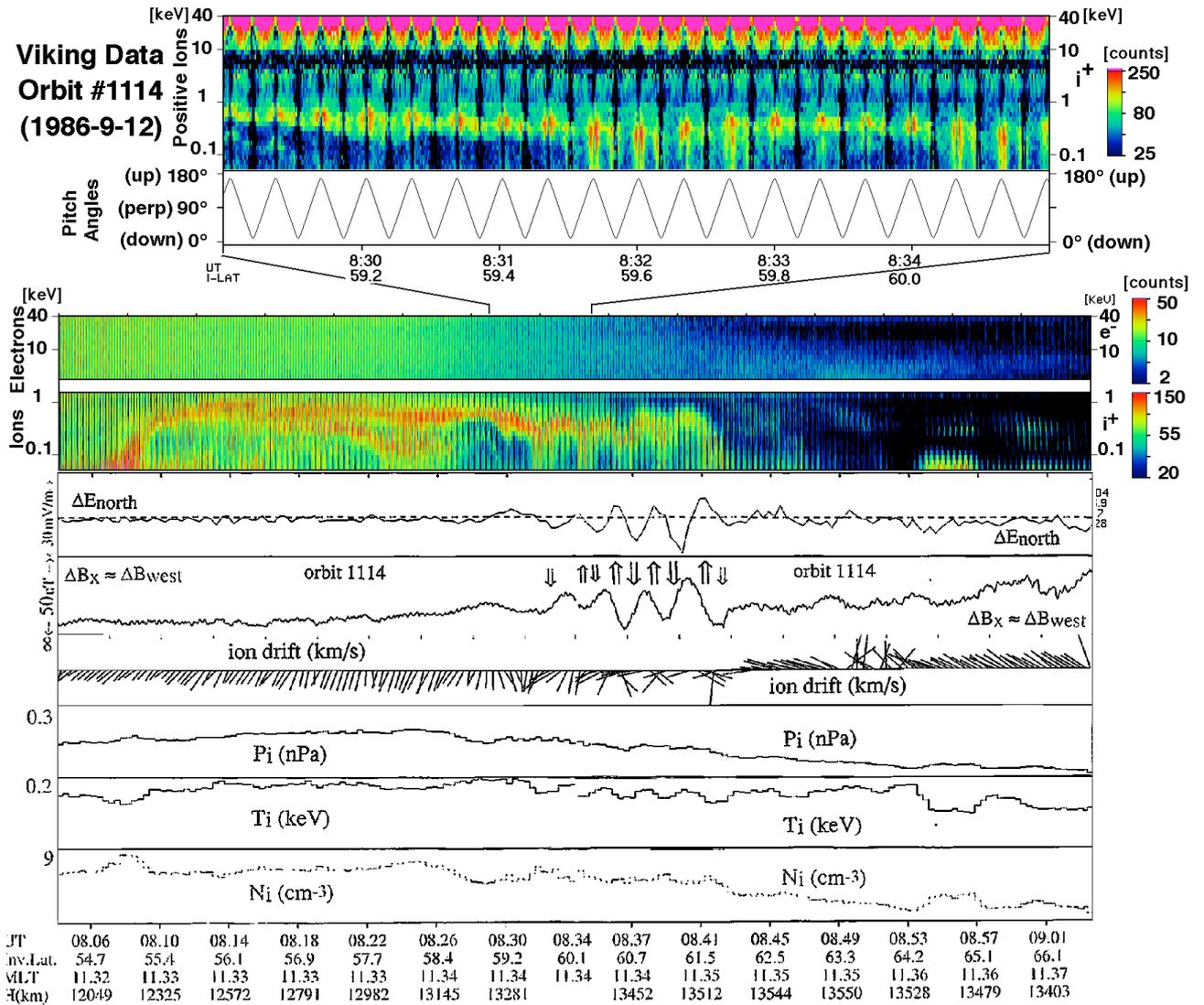


Plate 1. Viking data of orbit 1114 (September 12, 1986). The main panel shows from top row to bottom row high-energy (3-40 keV) electron spectrogram, low energy (50-1000 eV) ion spectrogram, electric field, magnetic field, and plasma moments calculated from the ion measurement. The other components of magnetic field are almost constant. The ion drift direction is obtained as an energy-integrated value, and it is not the same as the convection direction of the cold component. We can use it only as relative change of the drift in the present case. The unit for the particle measurement (counts) is proportional to the energy flux. The empty arrows in the magnetic field are the direction of the field-aligned current in case the variation includes some spatial structure. The upper small panel is an expansion of ion spectrogram at full energy range (50 eV - 40 keV). Ring current population is clearly seen in the ion detector. The electron detector does not have as good sensitivity as ion detector.

Figure 1. Dst index during the major magnetic storm on September 12, 1986. We observed strong DPS in orbits #1114 and #1115, but no such plasma is observed equatorward of the cusp in orbit #1113.

Figure 2. EISCAT chain and Nurmijärvi ground magneto-meter data (X component) close to the foot points of Viking satellite. The invariant latitudes of these stations are, from top to bottom, Sørøya (67.1°), Alta (66.3°), Kevo (65.7°), Muonio (64.8°), Pello (63.7°), and Nurmijärvi (57.7°). Tick marks are given every 50 nT. Note that the time resolution of Nurmijärvi data is one minute while that of the EISCAT magnetometer chain is 20 s.