Structures of Sub-keV Ions Inside the Ring Current Region

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Structured dispersive sub-keV ions inside the ring current region, or so-called wedge-like dispersions, those which have been considered signatures of long-time drift by ***ExB*** and grad-|***B***| drifts from nightside, are surveyed using the Viking, Freja, Munin, and Cluster satellites. While the ordinary wedge-like dispersion (increasing energy with increasing latitude) is observed mainly in the morning sector at all altitudes (by all spacecrafts), the reversed wedge-like dispersion (decreasing energy with increasing latitude) is observed at different local times by different spacecrafts. The differences between spacecrafts are also found in the H+/O+ ratio and in observation frequency. The observed altitudinal difference indicates that the evolution of drifting particles depends strongly on the mass and mirror altitude.

1. INTRODUCTION

Mid- and low-altitude satellites frequently detect dense trapped sub-keV ions with energy-latitude dispersive structures inside the dayside ring current region [Yamauchi et al., 1996a]. Figure 1 shows examples observed by the Viking satellite [Lundin et al., 1987]. One can recognize two major ion populations: the energetic (> 10 keV) ring current component, and the sub-keV component that we study in this paper. Located far equatorward of the auroral region, and clearly separated from the energetic component, the dense sub-keV trapped ions in Figure 1 have energy-latitude dispersive structures as marked by thick curves in the spectrogram. Such structured dense sub-keV ions in the ring current region are well recognized in almost all satellite data as a zoo of various dispersion patterns.

The independence of the sub-keV component from the energetic (> 3 keV) component seen in Figure 1 can also be seen in CRRES statistics of average pitch-angle distribution [Collin et al., 1993]. Multiplying the energy by their average number flux, the energy fluxes of sub-keV trapped ions (< 30 degree equatorial pitch angle in order to reach the Viking altitude) can often be higher than those of 2-3 keV range ions inside the ring current region (e.g., 5<L<6). Thus the sub-keV ions have different characteristics from the energetic (> 5 keV) ions in the ring current region.

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Ebihara et al. [2001] made the first attempt to simulate these dispersions seen in Figure 1. Since the drift motion of sub-keV ions are sensitive to both the ***ExB*** drift (eastward, energy independent) and grad-|***B***|/curvature drifts (westward for positive ions, energy dependent), the drift distance for a given elapse time becomes energy-dispersive. When looking at a fixed meridian, a different drift distance means a different L value, resulting in an energy-latitude dispersion. Thus the observed structures of sub-keV ions may directly reflect nightside electromagnetic disturbances, and hence studying the dispersion structures of the sub-keV ring current provides a new and good clue to understanding the dynamics of the inner magnetosphere.

However, very few studies have been done on this phenomenon. Energy dispersion signatures of trapped ions in the dayside subauroral region have mainly been discussed with the "nose" dispersion in the keV range [Smith and Hoffman, 1974; Ejiri et al., 1980], and with "bouncing ion clusters" that are interpreted as caused by the velocity-filter effect on the scale time of north-south bouncing period of ions [Quinn and McIlwain, 1979; see also Winningham et al, 1984], but not with the type demonstrated in Figure 1. There are several reports that discuss isolated regions of sub-keV plasma sheet-like ion precipitation in the plasmasphere [Shelley et al., 1972; Sauvaud et al., 1981; Chappel et al., 1982; Newell and Meng, 1986] with different terminology, but the relation between this "isolated plasma sheet" and the dispersed sub-keV ions in Figure 1 is not clear.

In this paper we study this phenomenon using different satellite (altitude) data. After we briefly review the phenomenon and formulate the problems in the next section, we compare the dispersion morphology and the local-time distribution between different satellites.

2. WEDGE-LIKE DISPERSIONS

The most commonly observed sub-keV ion structures in the ring current region in Viking data can be classified into three basic patterns: (a) wedge-like energy-latitude dispersion with increasing energy for increasing latitude as seen at 60-63 invariant latitude (ILat) in Figure 1 (generally at 57-67 ILat, and hereafter called "ordinary-wedge"), (b) the island-like energy-latitude dispersion seen at 64-69 ILat in Figure 1 (generally at 60-70 ILat, hereafter called "island-type"), and (c) reversed wedge-like dispersion with decreasing energy for increasing latitude seen at 68-72 ILat in Figure 1 (generally at 65-72 ILat, hereafter called "reversed-wedge"). Ebihara et al. [2001] named the ordinary-wedge "type-1", the reversed-wedge "type-3", and the combination of both "type-2" (hereafter called "bridge-type" dispersion). From a particle simulation viewpoint, the island-type was considered to be the same as type-2 with down-shifted energy in Ebihara et al. [2001]. The island-type often contains Pc-5 like wave structures as seen in the modulation of the upper energy cutoff, and one extreme case was reported in Yamauchi et al. [1996b].

Comparing ascending traversals and descending traversals of Viking [Yamauchi et al., 1996a], the observed dispersions of sub-keV ions are found to be spatial ones. The phenomenon is not observed for all traversals, yet intense ones are normally found for consecutive orbits (the Viking orbital period is a little more than 4 hours), indicating a 5-10 hour lifetime at a fixed longitude for intense events. Viking also revealed that the "ordinary-wedges" are primarily observed in the morning sector, whereas the "island-types" are primarily observed in the afternoon sector.

Freja (h=1700km) [Eliasson et al., 1994] also detected "ordinary-wedges" in a similar way to Viking (h=5000-13000 km): they are semi-stationary (similar lifetime in both satellites) and are observed mostly in the pre-noon sector [Yamauchi et al., 1996a]. However some differences exist: Freja did not observe the reversed-wedges, and it detected the ordinary-wedges nearly 10 degrees equatorward of what are observed by Viking. Freja detected the ordinary-wedges only during major magnetic storms whereas Viking detected the phenomena during all conditions of the geomagnetic activity (AE and Dst indices). The Freja observation also raised a question on the origin of ions because Freja registered the wedge-like dispersed sub-keV ions mainly in the oxygen channel with very faint signatures in the proton channel.

Using particle drift simulation ($\boldsymbol{E} \times \boldsymbol{B}$, grad-$|\boldsymbol{B}|$, and curvature: up to 2nd order invariant conservation), Ebihara et al. [2001] studied the wedge-like structures observed by Viking. They successfully reconstructed all types of dispersions (ordinary-wedge, reversed-wedge, and bridge-type) as signatures of past injections (10-20 hours before) of Maxwellian plasma from the night side. The location (found mainly in the pre-noon sector) and the dispersion patterns of the wedge-like dispersion can be explained as the result of the aforementioned drifts from the night-side intermittent injections with long elapse time (up to > 20 hours). However this study also raised new questions on the Viking and Freja observations of the wedge-like dispersions:

1. Why are only the "ordinary-wedges" observed by Freja, with latitude far equatorward of Viking's cases?

2. Why is it observed mainly in the oxygen channel by Freja?

3. Is the local-time distribution of Viking observations an artifact of the spacecraft orbit with > 10000 km altitude for morning-noon sectors and < 8000 km altitude for the evening sector?

4. Can all dispersion of sub-keV ions in the ring current region be explained by drifting particles originating from the nightside [cf., Høymork et al., 2001]? Is the island-type really a low-energy (long elapse time) variation of bridge-type dispersion?

With the above simulation and questions in mind, we study this phenomenon using different satellite (altitude) data. We re-examined the Viking PISP/ICS data [Lundin et al., 1987] and examined Freja TICS data [Eliasson et al., 1994], Munin MEDUSA data [Yamauchi et al., 2002], and Cluster CIS perigee data [Reme et al., 2001]. All instruments are covering sub-hundred eV to several tens of keV.

3. MUNIN AND CLUSTER OBSERVATIONS

Figure 2 shows examples of the ordinary-wedge and the reversed-wedge observed by Munin [Yamauchi et al., 2002] near its apogee of h=1800 km in the southern hemisphere. These dispersions are found only in the perpendicular (trapped) direction. Contrary to Freja, Munin at the same altitude detected the reversed-wedges. The observed dispersion morphology and latitudes are more similar to Viking cases than Freja cases despite its altitude.

The wedge-like dispersions inside the ring current region have recently been studied with Cluster perigee data [Reme et al., 2001; Vallat et al., 2002]. Cluster's perigee traversals are from southern hemisphere to northern hemisphere with perigee a little more than 4 Re at the equatorial plane (i.e., substantial L value). L=4 corresponds to 60 ILat and is low enough to cover most of the interesting region for the wedge-like dispersions. In fact we observed distinct structured sub-keV ions in more than half of the morning-noon traversals. Figure 3 shows examples.

Similar to Viking observations there are two major ion components, the energetic plasma sheet (ring current) component (around 5 keV near perigee) and the isolated sub-keV ions inside the cavity. The sub-keV component has an incomplete round-shape (corresponding to reversed-wedge) inbound and a complete round-shape (corresponding to bridge-type or island-type) outbound in the proton channel with faint oxygen signature at lower L. The three Cluster spacecrafts show similar patterns confirming that they are semi-stationary structures. However the inbound-outbound asymmetry in Figure 3 is not purely a spatial one: such asymmetry is found in many traversals. Out of nearly 200 traversals during 2001 and 2002, we observed 7/52/16 clear ordinary-wedge/reversed-wedge/bridge-type dispersions in southern inbound (24/14/36 in northern outbound) hemisphere, respectively.

Table 1. Satellite coverage and wedge-like dispersion.

S/C	coverage (height)	coverage (local time)	period	type	species
Viking	5000-13000 km	6-18 MLT	4.4 h	ordinary/reversed/island	H+ & O+ (?)
Freja	1700 km	all MLT	1.8 h	ordinary only (rare)	mainly O+
Munin	700-1800 km	early morning & late evening	1.8 h	ordinary/reversed	no composition
Cluster	4 Re at equator	all MLT	2.3 d	ordinary/reversed/island	mainly H+

Viking contains an ion mass spectrometer using ***ExB*** filtering, but the sensitivity of the mass spectrometer is not high enough to resolve the wedge-like structures at the sub-keV range. Figure 4 is one of the rare cases of the wedge-like structure resolved by the mass spectrometer. Corresponding to the 1 keV part of the ordinary-wedge seen in the total ion (top) panel, one can recognize dense proton and oxygen near 1 keV. Even the dispersion is recognized in the proton channel. Table 1 summarizes the observation by different satellites.

4. LOCAL TIME DISTRIBUTION

Figure 5 shows the local time distribution of the dispersed sub-keV ions in the ring current region observed by Viking, Freja, and Cluster. We registered only clear cases because some structures nearly always exist in this region [Yamauchi et al., 1996b; Vallat et al., 2002]. Both Viking and Cluster statistics show that the wedge-like dispersions are more commonly observed in the dayside than nightside in nearly 30-40% of traversals for clear cases. The probability is much lower for Freja observations (< 10% for all MLT).

The "ordinary-wedges" (without "reversed-wedges") are consistently found in the morning sector (6-12 LT) at all altitudes, supporting the scenario by Ebihara et al. [2001]. Here we identified wedge-like structures only inside the cavity; i.e., we excluded sub-keV ion dispersions extended from the energetic (plasma sheet) component at its higher-latitude ends (cf. at |Z|>1.5 Re of Cluster data in Figure 3) because we believe this component is different from the reversed-wedge dispersion predicted by the simulation. We also excluded from Cluster statistics the meso-scale sub-keV ion dispersions extended from the energetic (>5 keV) range into the cavity. This type is often found in the early morning sector, and will be discussed in a different paper. This exclusion probably accounts for the small discrepancy in the occurrence rate in the early morning sectors between Freja/Viking and Cluster.

The reversed-wedge is observed in a quite different way by different spacecrafts. Freja did not observe it whereas Munin observed it at the same altitude as Freja. Viking detection was mainly in the prenoon sector (both isolated cases and accompanied by the ordinary-wedge) whereas Cluster detection has a peak in the afternoon sector.

The "bridge-types" or "island-types" have slightly different local-time distributions between Viking (mainly island-types and observed near noon) and Cluster (mainly bridge-types and observed in the evening). We could not identify the corresponding phenomena in the Freja data. Since Freja can detect only intense ones during storms, this might indicates that only the ordinary-wedges were intensified during storms at this altitude, but not the island-types or reversed-wedges. The distributions of the bridge-type and the island-type are also slightly different by a few hours in local time according to Viking statistics. However we cannot discuss the relation between the island-type and the bridge-type unless we understand the differences between satellites.

5. DISCUSSION

The most puzzling fact is the composition: Cluster registered wedge-like structures mainly in the proton channel whereas Freja registered the phenomena mainly in the oxygen channel. Oxygen-dominant cases and co-populating cases exist for a significant number of traversals [Vallat et al., 2002], but the proton structures are normally much more intense than the oxygen structures in Cluster. When Viking can separate the mass (this is rare and is possible only for intense cases), it observed both protons and oxygen ions. So far we have two possible explanations: (1) high O+ concentration in the ring current and plasma sheet during magnetic storms [Lennartsson and Sharp, 1982; Hamilton et al., 1988]; (2) different drift velocity (L-cell and speed) and mirror altitude (H+ structure at L>5 and high altitude, and O+ structure at L<5 and low altitude) due to e.g., different pitch-angle distribution between H+ and O+ in the injection region. In fact one may assume $v_\perp > v_{//}$ for H+ (accelerated by ***JxB*** force in the tail), and $v_{//} > v_\perp$ for O+ (supplied along the geomagnetic field from the Earth). The storm-dependent scenario predicts simultaneous intensification of H+, O+, and O+/ H+ ratio when the wedge-like dispersion is intensified at high altitudes. The anisotropy scenario predicts a substantial O+ signature inside the H+ wedge at high altitudes. Neither is yet confirmed, and we need further studies.

The different local-time dependence of reversed-wedges (including bridge-type/island-type) for Viking and Cluster is also a puzzle. A simple altitude dependence scenario does not explain why we find reversed-wedges in Munin (h=1800km) data but not in Freja (h=1700km) data. If it depends on altitude, it must also depend on local time simultaneously in a complicated way. We might also have a basic identification problem of reversed-wedges for different altitudes: low-altitude (1000-2000 km), mid-altitude (5000-15000 km), and high-altitude (equatorial plane).

Another issue is the inbound-outbound asymmetry in the Cluster data. The majority of the ordinary-wedges and the bridge-types are found in outbound passes (northern hemisphere), whereas the reversed-wedges are more prominent in inbound passes (southern hemisphere). If the lifetime of the phenomenon is around 5-10 hours at one local time (as is indicated by calculation), one might be able to detect the temporal effect during traversals that take a few hours. This is related to the problem of identifying the reversed-wedges, because the high L-shell drift (corresponding to reversed-wedges) is faster than the low L-shell drift.

The last problem is the relation to substorms [e.g., Høymork et al., 2001]. Although the simulation by Ebihara et al. [2001] predicts wedge-like dispersion during long quiet periods after the substorm injection, not all substorms produce clear wedge-like structures afterward. This problem will be reported in a separate paper. One possibility is that bulk plasma injection may take place even during quiet geomagnetic conditions, and it does not have to be in the nightside. In fact we often observe signatures of local heating, i.e., non-dispersive ions as shown in Figure 6 (denoted as type-"mast"). Similar intense local heating signatures are found in Cluster too (not shown here).

6. SUMMARY

A comparative study of structured sub-keV ions (wedge-like dispersion) inside the ring current region was performed using Viking, Freja, Munin, and Cluster ion (composition) data as summarized in Table 1. We encountered several puzzles in interpreting the data although the majority of the wedge-like dispersions are basically consistent with the drift scenario proposed by Ebihara et al. [2001].

1. The wedge-like dispersion is detected mainly in the oxygen channel in Freja (h = 1700 km), and mainly in the proton channel in Cluster (h > 3 Re).

2. We might have a basic identification problem. While the ordinary-wedge (see Figure 1) is observed rather consistently at all altitudes, the reversed-wedge is observed in quite different ways between different satellites for local time distribution and observation frequency. The relation between the island-type and the bridge-type also remains unclear.

3. Cluster observations of wedge-like dispersion show an inbound-outbound asymmetry around perigee (near equator), which might reflect the temporal variation in the time scale of a few hours.

4. The relation to substorms remains unclear. The wedge-like dispersion might not necessarily originate from the nightside during substorms. A small yet significant portion of the structured sub-keV ions suggests local energization at dayside.

To solve these puzzles we definitely need more simulation (with anisotropic source distribution), further data analyses (e.g., fine classification and delay-time analyses versus geomagnetic indices), and analyses of data from different altitudes (FAST, Polar, Interball and new missions).

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REFERENCES

Chappell, C.R., J.L. Green, J.F.E. Johnson, and J.H. Waite, Jr, Pitch angle variations in magnetospheric thermal plasma: Initial observations from Dynamic Explorer-1, *Geophys. Res. Lett., 9*, 933, 1982.

Collin, H.L., J.M. Quinn, and J.B. Cladis, An empirical static model of low energy ring current ions, *Geophys. Res. Lett., 20*, 141, 1993.

Ebihara, Y., M. Yamauchi, H. Nilsson, R. Lundin, and M. Ejiri, Wedge-like dispersion of sub-keV ions in the dayside magnetosphere: Particle simulation and Viking observation, *J. Geophys. Res., 106*, 29571, 2001.

Ejiri, M., R.A. Hoffman, and P.H. Smith, Energetic particle penetration into the inner magnetosphere, *J. Geophys. Res., 85*, 653, 1980.

Eliasson, L., O. Norberg, R. Lundin, K. Lundin, S. Olsen, et al., The Freja hot plasma experiment - instrument and first results, *Space Sci. Rev., 70*, 563, 1994.

Hamilton, D.C., G. Gloeckler, F.M. Ipavich, W. Studemann, B. Wilken, and G. Kremser, Ring current development during the great geomagnetic storm of February 1986, *J. Geophys. Res., 93*, 14343, 1988.

Høymork, S., M. Yamauchi, Y. Ebihara, Y. Narita, O. Norberg, and D. Winningham, Dense ion clouds of 0.1-2 keV ions inside the CPS-region observed by Astrid-2, *Ann. Geophys., 19*, 621, 2001.

Lennartsson, W., and R.D. Sharp, A Comparison of the 0.1-17 keV/e ion composition in the near equatorial magnetosphere between quiet and disturbed conditions, *J. Geophys. Res., 87*, 6109, 1982.

Lundin, R., L. Eliasson, B. Hultqwvist, and K. Stasiewicz, Plasma energization on auroral field lines as observed by the Viking spacecraft, Geophys. Res. Lett., 14, 443, 1987.

Newell, P.T., and C.-I. Meng, Substorm introduction of ≤ 1 keV magne-tospheric ions into the inner plasmasphere, *J. Geophys. Res., 91*, 11133, 1986.

Quinn, J.M., and C.E. McIlwain, Bouncing ion clusters in the Earth's magnetosphere, *J. Geophys. Res., 84*, 7365, 1979.

Reme, H., C. Aoustin, J.M. Bosqued, I. Dandouras, B. Lavraud, et al., First multispacecraft ion measurements in and near the Earth's magnetosphere with the identical Cluster ion spectrometry (CIS) experiment, *Ann. Geophys., 19*, 1303, 2001.

Sauvaud, J.A., J. Crasnier, K. Mouala, R.A. Kovrazhkin, and N.V. Jorjio, Morning sector ion precipitation following substorm injections, *J. Geophys. Res., 86*, 3430, 1981.

Shelley, E. G., R. G. Johnson, and R. D. Sharp, Satellite observations of energetic heavy ions during a geomagnetic storm, *J. Geophys. Res., 77*, 6104, 1972.

Smith, P.H., and R.A. Hoffman, Direct observation in the dusk hours of the characteristics of the storm time ring current particles during the beginning of the magnetic storms, *J. Geophys. Res., 79*, 966, 1974.

Winningham, J.D., J.L. Burch, and R.A. Frahm, Bands of ions and angular V's: A conjugate manifestation of ionospheric ion acceleration, *J. Geophys. Res., 89*, 1749, 1984.

Vallat, C., I. Dandouras, G.K. Parks, M. Wilber, M. Dunlop, L. Kistler, H. Reme, A. Balogh, New ionic structures observed in the equatorial ring current during CLUSTER perigee passes, presentation at AGU meeting, San Francisco, Dec. 2002

Yamauchi, M., R. Lundin, L. Eliasson, and O. Norberg, Meso-scale structures of radiation belt/ring current detected by low-energy ions, *Adv. Space Res., 17, (2)*, 171, 1996a.

Yamauchi M., R. Lundin, K. Mursula, G. Marklund, and T.A. Potemra, Dayside Pc5 pulsation detected by Viking ion data at L=4, *Geophys. Res. Lett., 23*, 2517, 1996b.

Yamauchi, M., O. Norberg, S. Barabash, R. Lundin, and D. Winningham, Mission and science of Munin: The first Swedish nano-satellite, *23rd ISTS proceedings*, 2010, 2002.

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Cluster	4 Re at equator	all MLT	2.3 d	ordinary/reversed/island	mainly H+

Figure 1. Viking energy-time spectrograms for electrons (0.3-40 keV) and positive ions (0.05-40 keV) for 1986-9-1 (orbit 1053). Unit is the normalized count rate which is proportional to the energy flux. The ion instrument is composed of 2 sensors: one for keV range and the other for sub-keV range. The radiation belt (MeV electrons) can be identified by keV electrons.

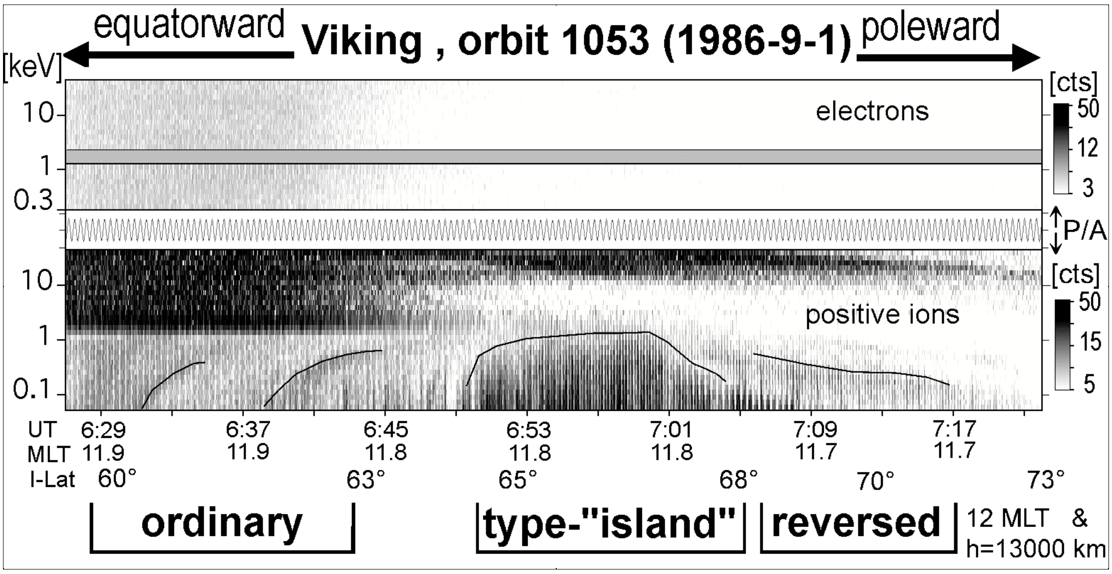
Figure 2. Munin energy-time energy flux spectrograms for positive ions (0.002-10 keV) for (a) 2000-12-11 and (b) 2001-1-11. Upper, middle, and lower panels show ions parallel, perpendicular, and anti-parallel to the geomagnetic field, respectively. The vertical blackout lines are due to interference.

Figure 3. CIS (Cluster Ions Spectrometry) energy-time energy flux spectrograms for positive ions (0.02-40 keV) for 2001-8-21. Proton data from the other two spacecrafts during the same UT range are also shown.

Figure 4. Viking energy-time spectrograms for total positive ions (0.1-10 keV), protons (0.2-10 keV), and oxygen (0.8-10 keV) for 1986-9-23 (orbit 1175).

Figure 5. Local time distribution (3 hours bins) of the wedge-like dispersion signature (clear cases only) inside the ring current region. (a) Viking (more than 700 traversals); (b) Freja (more than 6000 traversals); (c) Cluster (nearly 400 traversals). Freja covered all local times rather uniformly at a nearly fixed altitude, making the raw number almost proportional to the probability. For Viking and Cluster cases we took probability of the phenomenon clearly seen during a traversal which covers from at least < 67 ILat.

Figure 6. Viking energy-time spectrograms for electrons (1-40 keV) and positive ions (0.05-10 keV) for 1986-5-12 (orbit 436).



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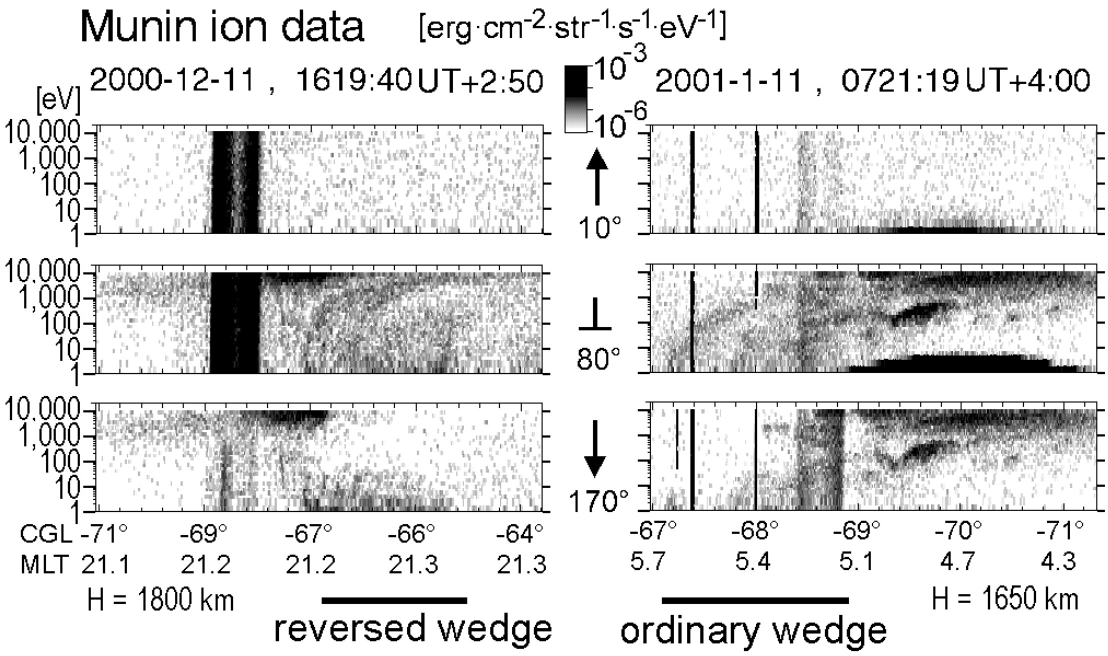

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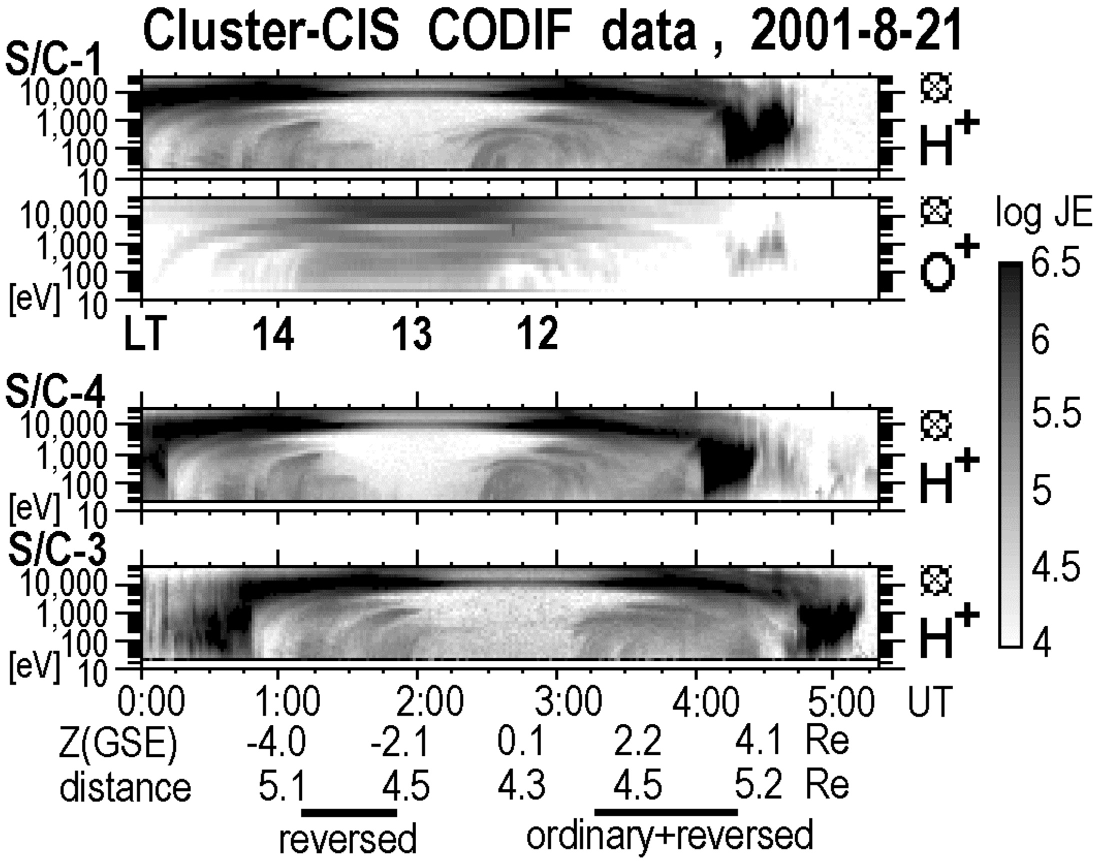

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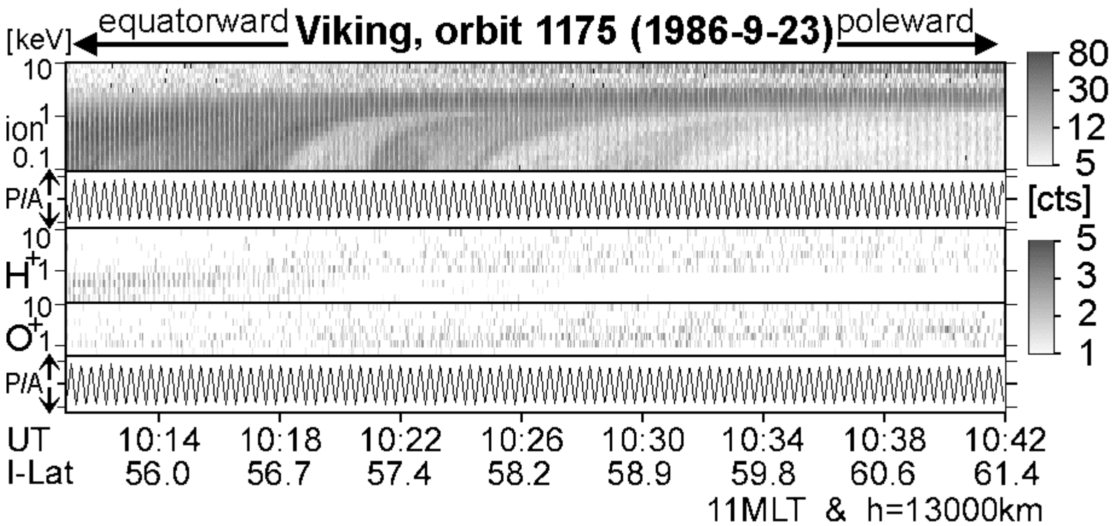

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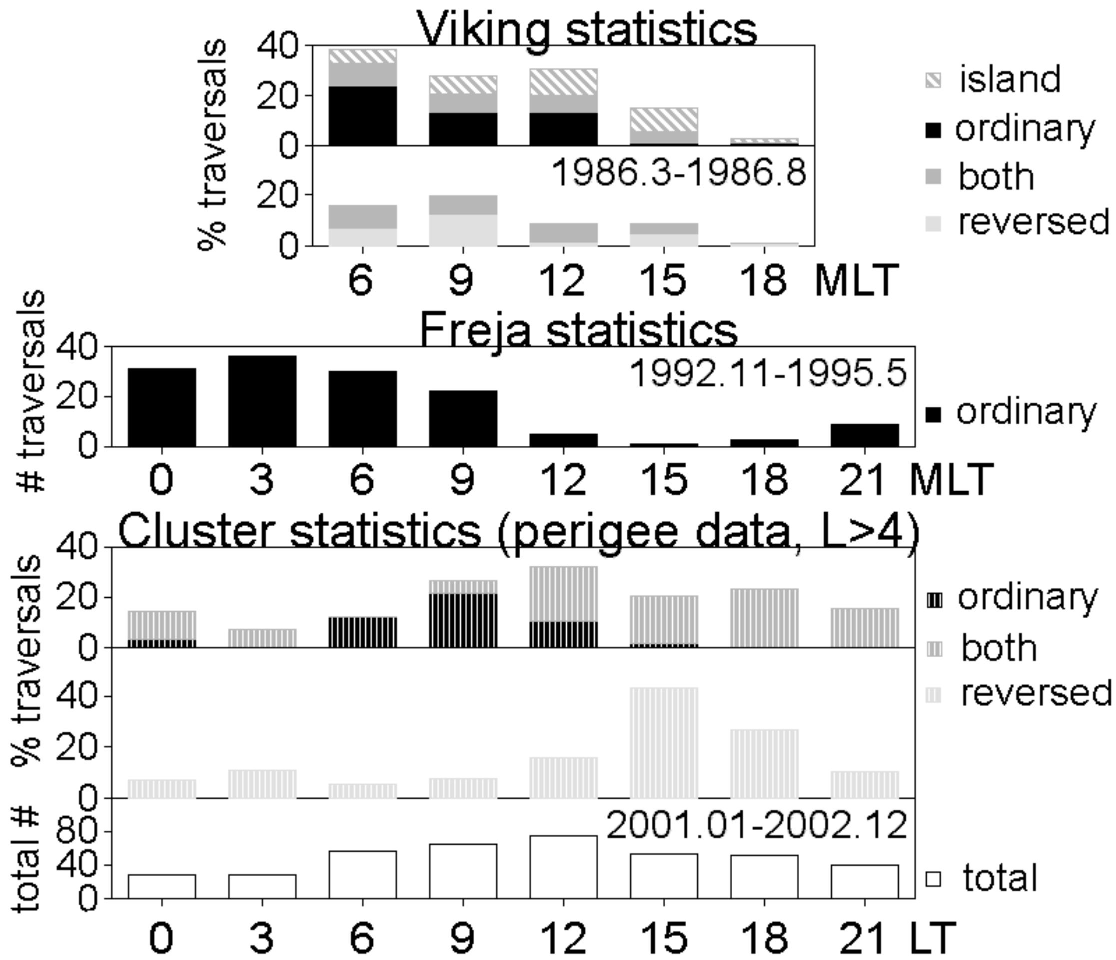

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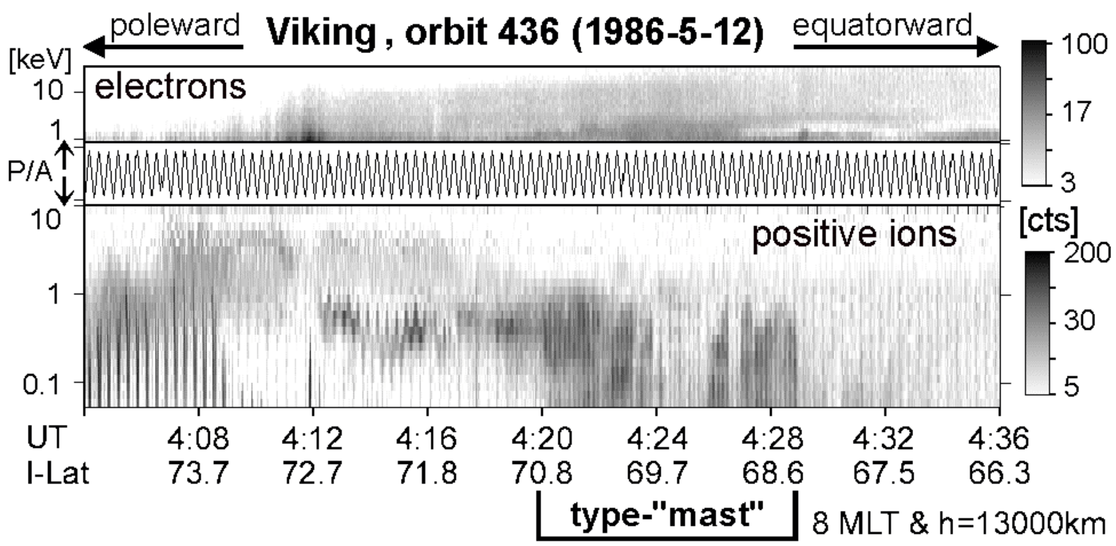

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