AVERAGE ENERGY DISTRIBUTIONS OF ENERGETIC IONS IN THE DIFFERENT PARTS OF THE CUSP/CLEFT REGION

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Abstract

We have studied the energy distributions of energetic ions in the mid-altitude cusp/cleft region using measurements by the Magnetospheric Ion Composition Spectrometer (MICS) on the Swedish Viking satellite. The MICS instrument can distinguish between H^+, He^+, He^{++}, and O^+ ions in the energy/charge range from 10 to 326 keV/e. Dividing the mid-altitude cusp/cleft region into four different parts (cusp, cusp proper, cleft and mantle) in the way introduced by Kremser and Lundin (1990), we have accumulated data from 38 Viking orbits passing over the dayside cusp/cleft region, and calculated the energy distributions for the four ion species in each of these four parts separately. The results show that the energetic ion populations in the cusp, cusp proper and cleft resemble each other very much, whereas the ion intensity in the mantle is very low and some of the energy distributions there have different properties from those of the other regions. O^+ ions seem to be a substantial component in the cleft, cusp and cusp proper. The energy distributions of the H^+ and particularly the He^{++} ions resemble a κ-distribution, while all other ion distributions are well fitted by a power-law function.

1. Introduction

Several different parts of the magnetospheric boundary layer are, because of topological reasons, closely connected in the cusp/cleft region. Particle populations of magnetospheric and magnetosheath origin can be found there coexisting over a small spatial area. Therefore, the cusp/cleft region has received a considerable amount of interest during the last few years (for a review and references, see e.g. Lundin, 1988). It has been studied, for example, by the Swedish Viking satellite (for a review of the Viking project, see e.g. Hultqvist, 1990).

Recently, Kremser and Lundin (1990) divided the mid-altitude cusp/cleft region into four different areas, which they called the cusp, cusp proper, cleft and mantle. This division was made on the basis of the presence of ions and electrons of magnetosheath origin, with average energies of the order of 1 keV and 100 eV, respectively, and of electron acceleration signatures. Accordingly, the cusp and cusp proper are defined to be areas where both magnetosheath ions and electrons are present, the former area showing in addition important electron acceleration signatures that are lacking in the latter area. The cleft is defined as a region void of magnetosheath ions. On the other hand, the mantle, which, on the average, is more poleward than the other three areas, contains magnetosheath ions but no magnetosheath electrons. Outside the mid-altitudes, these areas are expected to be connected to the exterior cusp, the entry layer, the low-latitude boundary layer and the plasma mantle, respectively.

Kremser and Lundin (1990) studied the average properties of energetic electrons and ions in the four cusp/cleft areas accumulating data from more than 100 Viking cusp crossings. They used the ICS 3 and ESP 5 sensors of the V3 hot plasma instrument (for a review, see e.g. Sandahl *et al.*, 1985) on the Viking spacecraft, which cover the elecron energies from 7 to 97 keV and ion energies from 2 to 60 keV/e. In the present paper we extend this analysis by studying the average energy spectra of energetic ions in the various cusp/cleft regions using the measurements obtained by the Magnetospheric Ion Composition Spectrometer (MICS) onboard the Viking satellite. These measurements extend to higher energies than the earlier cusp/cleft studies, and give evidence for the existence of four types of energetic ions in these regions: H^+, He^+, He^{++}, and O^+ ions.

2. Instrument and data

The MICS instrument (Stüdemann *et al.*, 1987) consists of an electrostatic analyzer, a time-of-flight unit and a solid state detector. It could determine the mass, energy and charge state of ions, and, in particular, distinguish between H^+, He^+, He^{++}, and O^+ ions. The energy ranges measured by the MICS instrument were 35–326 keV for H^+, 38–326 keV for He^+, 20–752 keV for He^{++}, and 12–326 keV for O^+ ions.

For this analysis we have accumulated data from 38 Viking orbits passing over the cusp/cleft regions between April 24 and August 5, 1986. This is a subset of those orbits studied by Kremser and Lundin (1990) with the additional requirement that the MICS instrument was working. The Viking orbit numbers included in this analysis are 502, 518, 524, 530, 536, 540, 546, 552, 562, 568, 574, 580, 584, 590, 592, 602, 612, 646, 662, 668, 734, 748, 814, 820, 822, 826, 836, 838, 840, 842, 858, 860, 866, 880, 882, 892, 896, and 904. One did not observe all the four areas during all the crossings. Alas, the cusp was observed in 37 orbits, the cusp proper in 24 orbits, the cleft in 25 orbits, and the mantle in 20 orbits. Altogether the data set consists of 7.05 hours of data from the cusp, 2.89 hours from the cusp proper, 3.82 hours from the cleft, and 3.86 hours from the mantle. We have calculated the average differential flux densities (in brief fluxes) of the four ion species in the four different regions, adding up the contributions from all the relevant orbits, and summing over the pitch-angles.

3. Energy distributions

3.1 Cusp (Figure 1)

Fig. 1. shows the fluxes of the four ion species and their 1σ error curves for the cusp as a function of the particle energy. The proton distribution shows an approximate power-law behaviour with, however, some indication of a Maxwellian or κ-type curvature at the lowest energies. The exponent of the distribution, when fitted to a power-law function $j \propto E^{-\alpha}$, is α=-4.1 ±0.1. The absolute value of the proton flux, particularly at low energies, is larger than for any other ion species in the cusp.

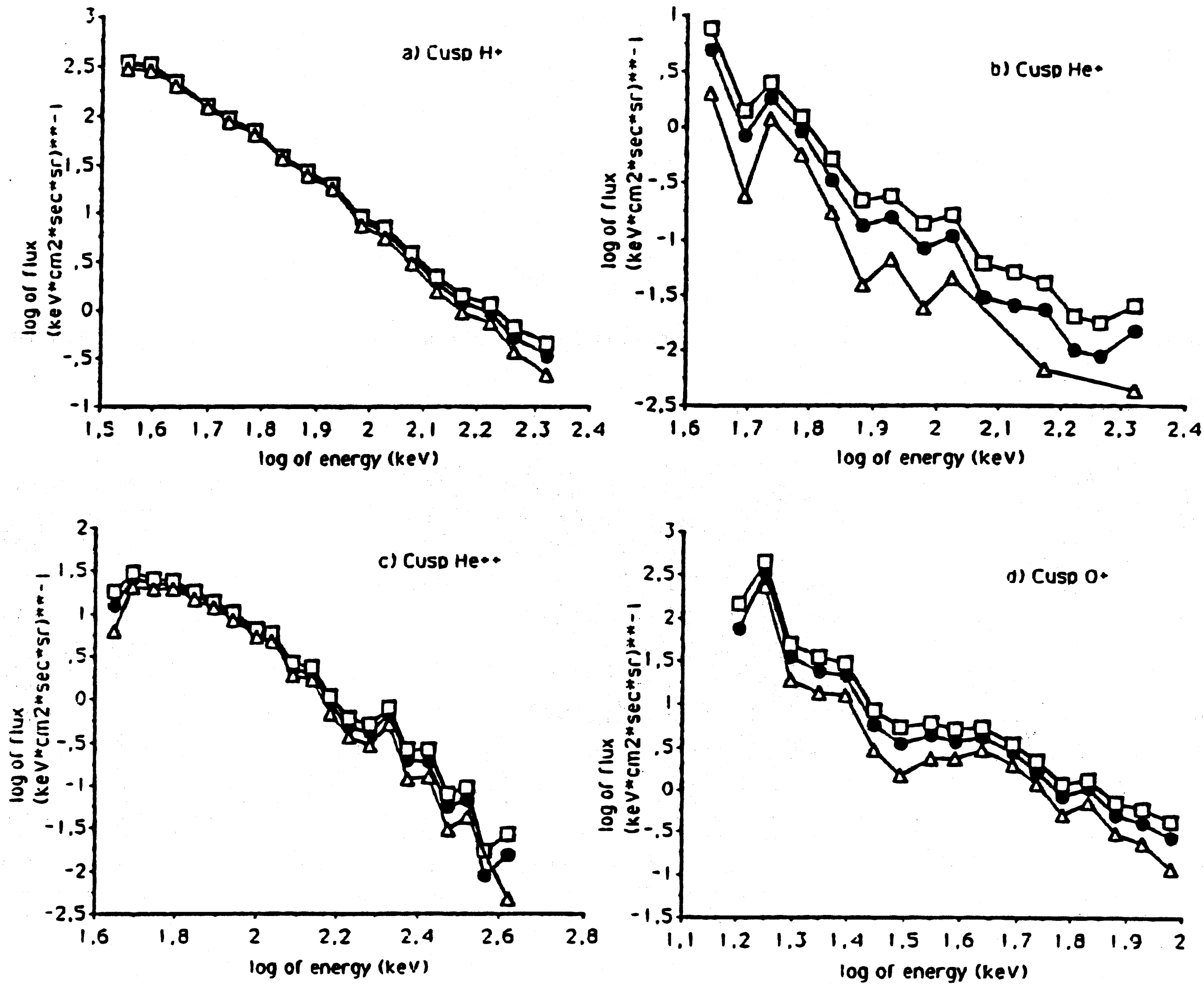

Figure 1. The differential flux densities of the four ions observed in the cusp and their 1σ upper and lower error curves as a function of the particle energy (in keV).

The statistical uncertainties are much larger for He^+ than for H^+, but the overall power-law behaviour can still be recognized with an exponent α=-3.9 ±0.3. On the other hand, the He^{++} flux deviates clearly from the pure power-law distribution. It resembles a κ-like distribution with a maximum around 20–35 keV and a power-law tail with an exponent α=-4.3 ±0.35 beyond about 100 keV. There may be some indications for a new structure at around 200 keV, but the statistical uncertainties are already quite large at such high energies. Note also the large absolute value of the He^{++} flux, which, at the highest energies studied, competes with the proton flux.

We have also found a considerable amount of O^+ ions in the cusp, for which a power-law distribution gives a fairly good fit with an exponent α=-3.0 ±0.25. However, when the data are analyzed in more detail, there may be some indication for a steeper power-law distribution at low energies, and a Maxwellian distribution with a maximum at around 40 keV. Yet, poor statistics, particularly due to the low detector efficiency for O^+ ions below 20 keV, deny a definite conclusion on the existence of two separate populations.

3.2 Cusp proper (no figure)

The ion energy distributions in the cusp proper are similar to the corresponding ones in the cusp. The H^+, He^+, and He^{++} fluxes in the cusp proper are slightly higher than in the cusp. The proton energy spectrum, fitted with a power-law function, yields an exponent α=-4.4 ±0.2. However, as for the case of the cusp, the proton distribution also shows some indications for a Maxwellian behaviour at low energies.

The He^+ flux in the cusp proper has a similar power-law distribution as in the cusp with an exponent α=-4.0 ±0.5, while the He^{++} flux has again a κ-like distribution. However, in comparison to the cusp, the maximum of the He^{++} distribution is below the energy range studied, and there is no indication for a new structure at high energies. The high energy power-law tail of the He^{++} distribution has an exponent α=-4.8 ±0.4.

The O^+ flux is of the same order of magnitude as in the cusp, and has a power-law behaviour with an exponent α=-3.2 ±0.2. There is again a slight indication for a Maxwellian distribution centered around 35–40 keV, but now the slope at low energies does not deviate from the overall slope.

3.3 Cleft (no figure)

The largest ion fluxes are found in the cleft. The He^+ and O^+ fluxes are somewhat higher than in the cusp proper, whereas other ion fluxes are roughly as large. The proton flux has again an approximate power-law form with an overall exponent α=-4.5 ±0.4.

The exponent of the power-law spectrum of the He^+ flux is α=-4.45 ±0.4. The He^{++} flux for the cleft also resembles that of the cusp and cusp proper with a maximum at low energies, and an approximately equal exponent α=-4.5 ±0.2 for the high energy tail.

The O^+ flux is again fairly well fitted by a power-law function with an overall exponent α=-3.3±0.3. However, as for the cusp, there is some indication for a separate high energy population with a maximum at roughly the same energy.

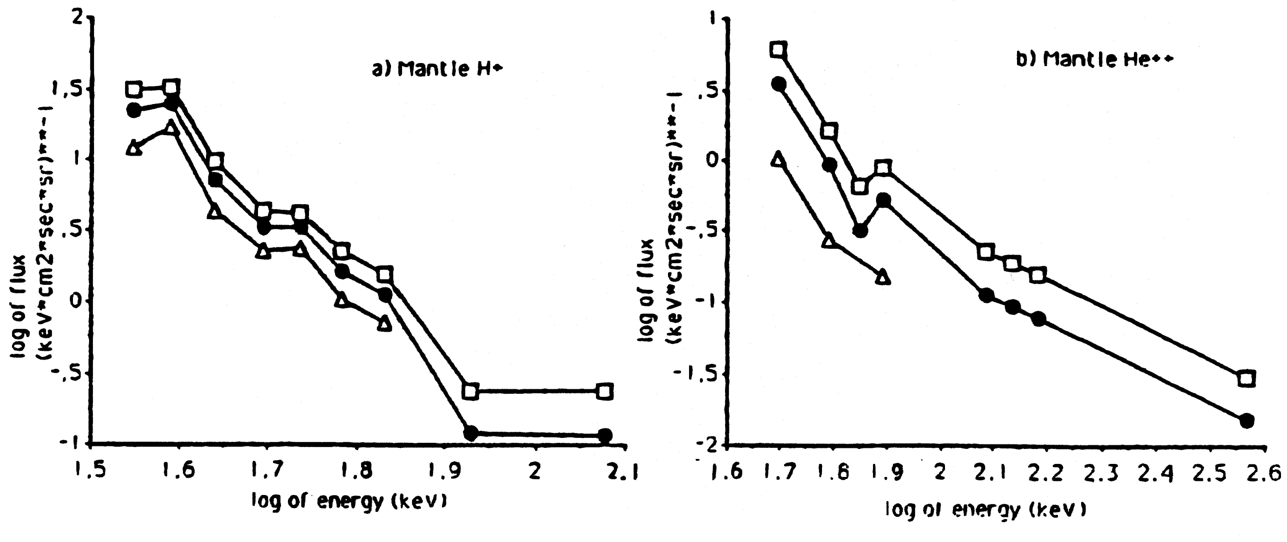

Figure 2. The same as Fig. 1 now for the mantle, where only protons (a) and alpha particles (b) were observed.

3.4 Mantle (Figure 2)

Whereas the ion populations in all the other areas more or less resemble each other, the distributions in the mantle are different in some respects. For the mantle, we can reliably identify only the protons and alpha particles which have considerably smaller fluxes than in the other areas. Fig. 2. shows the H^+ and He^{++} fluxes for the mantle. Irrespective of rather large statistical fluctuations and some data gaps at higher energies, the H^+ and He^{++} fluxes can both be fitted well by a power-law distribution with overall exponents α=-4.8 ±0.5 and α=-2.5 ±0.3, respectively. For the fluxes of the He^+ and O^+ ions we can only give upper limits. A very rough estimate is that their fluxes must be at least one order of magnitude smaller than for the cusp.

4. Discussion and conclusions

We have summarized in the Table our results for the exponents α obtained when fitting the differential fluxes of the various ions with a power-law function. The fitting was done for the He^{++} ions using only the high energy tail above about 100 keV, but for all other ions the whole energy spectrum was used.

	H^+	He^+	He^{++}	O^+
Cusp	- 4.1 ± 0.1	- 3.9 ± 0.3	- 4.3 ± 0.35	- 3.0 ± 0.25
Cusp proper	- 4.4 ± 0.2	- 4.0 ± 0.5	- 4.8 ± 0.4	- 3.2 ± 0.2
Cleft	- 4.5 ± 0.4	- 4.45 ± 0.4	- 4.5 ± 0.2	- 3.3 ± 0.3
Mantle	- 4.8 ± 0.5	–	- 2.5 ± 0.3	–

Table. The exponents α of the ion fluxes in the four areas fitted by a power-law function. For He^{++} ions the fit has been done to the high energy tail of the spectrum, for all other ions to the whole spectrum.

We have seen that the energy distributions of the energetic ions in the cusp, cusp proper and cleft are fairly similar, but deviate in some respects from those of the mantle. This similarity can well be seen in the proton fluxes, which have nearly equal intensities in all the three areas. However, for this ion species, the form of the distribution and its power-law exponent are roughly the same also in the mantle. It is most probable that the protons belong to the same population whose origin may be the ring current.

The He^+ fluxes have similar power-law energy spectra in the three areas, and the exponents are nearly the same as those for the protons. This is a strong indication for a common source for He^+ ions and the protons.

The He^{++} fluxes in the cusp, cusp proper and cleft deviate clearly from a power-law distribution at the lowest energies studied, and show a maximum around 25–40 keV. The high energy tail exponents are also nearly the same as for the protons. Note that the He^{++} intensities get very high at the highest energies, comparable to those of the proton flux. However, the He^{++} population of the mantle seems to have different characteristics. It has a simple power-law differential spectrum with an exponent value which differs from that of the other areas. It is probable that this population has not the same source as the He^{++} ions found in the other three areas.

Irrespective of some indications for a more complicated structure, the O^+ ion fluxes found in the cusp, cusp proper and cleft are well fitted by a power-law distribution. However, it is very interesting to note that the exponents of all the O^+ spectra are consistently smaller (in absolute magnitude) than for the other ions. If the O^+ ions also come from the ring current, they must have experienced more acceleration after leaving the source region than the other ion species on the average. If one compares the exponents of the He^+ and O^+ fluxes in the three areas, one can distinguish a tendency in the way that the exponents for the cleft, which is the most equatorward part of the cusp/cleft region, are slightly larger in absolute magnitude than for cusp or cusp proper. This may be an indication that, if all the ions have the same origin, there is a mechanism which accelerates the ions on their way to the cusp/cleft region, and that this mechanism is the more effective the larger the ion mass (or mass/charge) is. Of course, on the basis of this analysis, a completely different, e.g. ionospheric, origin can not be excluded.

Christon et al. (1989) have studied the energy distributions of the plasma sheet ions during undisturbed geomagnetic times. They have found that the ion fluxes have a power-law high energy tail, and that the exponents of the distributions for all ions are in the range 4–8 (more definitely 5–6). The exponents that we have found for the ion fluxes in the different parts of the cusp/cleft region are at the lower limit of this range. This may give additional support for the assumption that ions are accelerated when drifting towards the higher latitudes.

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