Development of medium energy ion mass spectrometer for the exploration of the earth's magnetosphere

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In the past decades, space plasmas have been extensively investigated by satellite-borne in-situ measurements. They revealed that charged particles have a broad energy range from less than 1[eV] up to more than 10[MeV] and they form a number of plasma structures in the earth's magnetosphere. However, acceleration processes and transport of mass, momentum, and energy in the magnetosphere is not fully understood.

For instance, the earth's ring current ions are characterised by energy of ~10-~200[keV], while typical energies of ions in the ionosphere and solar wind are considerably lower (less than 1[eV] and ~1[keV/nuc], respectively), though they are considered to be the source particles. Thus, build-up processes of the ring current are the subjects of intensive research.

The particle acceleration via magnetic reconnections also attracts the attention of many researchers. The energy of ions that is highly accelerated in the reconnection regions sometimes exceeds ~40[keV]; protons with Alfven velocities are not consistent with such high energy flows.

In order to study these key regions, in-situ observations with continuous coverage of low (~[eV]) to medium (~10-~200[keV]) or to even higher energies are necessary. In fact, ERG and SCOPE missions are planned to explore the above regions with plasma instrument packages that cover the most part of the energy range (from ~10[eV] to more than ~1[MeV]). However, despite their importance, measurement techniques of medium energy ions are not well established due to technical difficulties.

In addition, it is extremely important to simultaneously measure energy (E), mass (m), charge state (q) of each ion for the investigations of the transport processes and energisation mechanisms of ions. Mass and charge state of each ion provide information on their origins (solar wind or the terrestrial ionosphere). Furthermore, measurements of their three-dimensional distribution functions are also required, since waves generated by ion temperature anisotropy possibly affect the energy budgets of the ring current and the spatial/temporal evolution of radiation belt electrons.

An efficient technique to obtain these data is the combination of an electrostatic analyser (ESA), a time-of-flight mass spectrometer (TOF), and solid-state detectors (SSDs). They can simultaneously and independently measure energy-per-charge (E/q), velocity (v), and energy (E) of incoming ions, respectively; E, m, and q can be deduced from the above information. However, ESA has been mostly used for the low energy range (less than~40[keV]) and increases in size with increasing upper limit of measurement energy, due to the design principle. Therefore, in the case of medium energy range, it is not easy to obtain appropriate performances within practical size suitable for satellite observations.

In order to solve the size issue, a novel cusp type electrostatic analyser is proposed. This design provides us a relatively small instrument that has an energy range up to ~200[keV/q] with a full solid angle coverage (by using of S/C spin). On the basis of this sophisticated idea, characteristics of the instrument have been studied in detail with numerical simulations, and then the test model design was decided; its sensitivity, energy resolution, angle resolution, and size are sufficient to explore the inner magnetosphere of the earth. Laboratory experiments of the test model show good agreement with the numerical simulations. An EUV rejection property has also been confirmed by the experiments.

The TOF unit has also been designed. Results of computer simulations show the sufficient mass resolution to discriminate all major ions in the terrestrial magnetosphere, such as H+, He++, He+, O2+, and O+.