論文内容の要旨

論 文 題 目　　**Study of Magnetospheric Energetic Particles: Satellite Observations, Lessons for the Future, and Development of Medium-Energy Plasma Instruments**

(磁気圏における中間・高エネルギー粒子の動態に関する研究：衛星観測と将来探査への教訓，及び中間エネルギープラズマ観測器の開発)

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Since the first particle measurements done half a century ago, space plasmas have been extensively investigated by satellite-borne in-situ observations. They have revealed that charged particles have a broad energy range from <1 eV up to >10 MeV in/around the Earth's magnetosphere; these plasmas form various structures in multiple scales, and often shows dynamic processes over a variety of time scales. The energy of source plasma is rather lower. Thermal energy of ionospheric particles is <1 eV, while solar wind electrons and ions have typical energies of ~10 eV and ~1 keV/nuc, respectively. Therefore, it can be said that the terrestrial magnetosphere acts as a charged particle accelerator. It can also be applied to other Magnetospheres, such as Jovian and Kronian ones. However, details of particle acceleration processes and large-scale transport of mass and energy are not fully understood. Studying energetic particles in/around magnetospheres is important in order to clarify the mechanisms of such huge particle acceleration systems in space. The main objectives of this study are to develop innovative energetic plasma instruments (5-200 keV/q) for space exploration missions of a new era, as well as analysing energetic particle data obtained by currently-operating satellites. During a storm recovery phase on 15 May 2005, the Geotail spacecraft repeatedly observed high-energy (>180 keV) oxygen ions in the dayside magnetosheath near the equatorial plane. The focused time period is when Geotail observed the oxygen ions

and the interplanetary magnetic field (IMF) was constantly northward. The magnetic reconnection occurrence northward and duskward of Geotail is indicated by the Walén analysis and convective flows in the magnetopause boundary layer. Anisotropic pitch angle distributions of ions suggest that high-energy oxygen ions escaped from the northward of Geotail along the reconnected magnetic field lines. From the low-energy particle precipitation in the polar cap observed by DMSP that is consistent with magnetic reconnection occurring between the magnetosheath field lines and the magnetospheric closed field lines, it is concluded that these oxygen ions are of ring current origin. The results thus suggest a new escape route of oxygen ions during northward IMF. In the present event, this escape mechanism is more dominant than the leakage via the finite Larmor radius effect across the dayside equatorial magnetopause. Lessons from the past/present observations and future perspectives are discussed in the middle of this thesis. It is intensively argued that the energy coverage in plasma measurements, including medium-energy range (5-200 keV/q), is significant for future explorations of Earth and Planetary magnetospheres. In fact, detailed discussion on number/energy fluxes in the above event study on the oxygen ion escape was difficult due to the poor energy coverage (and no mass discrimination in the low-energy range). The instruments should cover full solid angle with higher and more reliable sensitivity than that of previous ones. It is also pointed out that noise attenuation is indispensable for inner magnetospheric explorations and observations during solar energetic particle events. The importance of the medium-energy particle measurements in the planetary magnetospheres is also discussed. In order to achieve the full energy coverage in future observations, a new electrostatic analyser (ESA) that enables medium-energy particle measurements is proposed. The design of a test model realises the uppermost measurement energy of ~200 keV/q with applied high voltage of ±5 kV (the maximum electric field in the curved plates of 2 kV/mm avoids the risk of the discharge). Full solid-angle coverage is achieved by its novel structure. Laboratory experiments with the test model analyser show that its performance agrees with numerical simulations. The design is well suited for combination with a mass analysis unit, while the novel design can also be applied to medium-energy electron measurements. Along with energy analysis, the mass discrimination and the charge state identification are important for ion measurements. Therefore, a combination of ESA, time-of-flight (TOF) mass analysis unit, and the solid-state detectors are utilised. ESA determines energy-per-charge (E/q) of each incoming ion, TOF provides the ion velocity (v), and the solid-state detector measure total energy of each ion (E); those independent determinations unambiguously give ion energy (E), mass (m), and charge state (q). A sophisticated ion mass spectrometer for medium-energy range (~10-200 keV/q) is also developed. The wide field-of-view (~360° fan) enables acquisition of 3-D distribution functions for all the major ions, by utilising spacecraft spin motions. The mass analysis unit that measures ion TOF is designed to detect secondary electrons by a single microchannel plate, which realises a lightweight and a simple structure. Laboratory experiments with a test model show that the performance of mass spectroscopy agrees with numerical simulations. For charge state measurements of medium-energy ions, a single-sided silicon strip detector is newly applied. Based on laboratory experiments, it is shown that the detector has low noise levels which provide sufficient energy resolutions for charge state measurements of medium-energy ions. It is also demonstrated that energy loss at a dead-layer is a critical factor for energy resolution and measurement energy threshold. It is found that a thickness of the dead-layer is ~370 nm, and concluded that the thinner dead-layer would provide the better performance for the heavy ion detection. Single-sided silicon strip detector with a thin dead-layer is a crucial technique for medium-energy ion measurements in the next generation satellite-borne missions. Design of a medium-energy electron instrument (~5-80 keV) is also presented. Serious problem in electron measurements in the radiation belt is the background noise. High-energy particles penetrating the sensor shielding generate spurious signals, and their count rate can be comparable to that of the true signals. Ion instruments with mass analysis units can reject the spurious signals by taking double coincidence of the secondary electron signals, while electron instruments cannot. In order to attenuate such background noise during medium-energy electron measurements, the double energy analyses (DEA) method is proposed. DEA is conducted by a combination of an electrostatic analyser and avalanche photo-diodes (APDs); ESA and APD independently determine the energy of each incoming particle. By using the DEA method, therefore, the penetrating particles can be rejected when the two energy determinations are inconsistent; spurious noise are caused only when the deposited energy at an APD is by chance consistent with the measured energy by ESA. The noise count rate is formulated and the advantage of DEA method is shown quantitatively. Medium-energy ion/electron instruments presented in this thesis will surely be appreciated for upcoming space missions that will observe energetic plasma structures/phenomena of Earth and other planetary magnetospheres.