論文内容の要旨

論文題目　Structure and Dynamics of the Lunar Ionized Exosphere
（月希薄電離大気の構造とダイナミクスに関する研究）

氏　名　田中　孝明

The Moon is surrounded by extremely tenuous alkali atmosphere. The atmosphere is enough thin to be regarded as exosphere which called surface-bounded exosphere (SBE). The alkali components such as Na or K have been observed in order to understand the generation process and the transport mechanisms. The continuous ground-based observations and laboratory experiments have confirmed that the alkali exospheric components are produced by ion-induced desorption (sputtering), photon-stimulated desorption (PSD), meteoriteinduced vaporization and thermal desorption from the surface. The major loss process of the exospheric particles is photoionization and ion-pickup process. The ion-pickup process is quite simple because the Moon has no global dipole magnetic field. The ionized exospheric particles are transported by the motional electric field $E = -V_{sw} \times B_{sw}$ where $V_{sw}$ is the solar-wind bulk velocity and $B_{sw}$ is the interplanetary magnetic field. If we know the electric field, it is possible for us to trace back the ion trajectory and to know where these ions are produced. Though it has been observed by ground-based technique on many occasions since its discovery, in-situ observation of the lunar ions by satellite-borne plasma instruments is quite rare. In-situ observation is another complementary way to study the lunar exosphere because the detected ions include information of the exosphere.
Japanese lunar orbiter SELENE (KAGUYA), which was launched on September 14,

2007, has the in-situ plasma analyzers named MAP-PACE (MAgnetic field and Plasma experiment - Plasma energy Angle and Composition Experiment) in order to investigate the plasma environment at 100km altitude around the Moon. PACE consists of two sensors for low energy electron measurements: ESA (Electron Spectrum Analyzer)-S1, ESA-S2 and two sensors for low energy ion measurements: IEA (Ion Energy Analyzer) and IMA (Ion Mass Analyzer). SELENE is a three-axis stabilized satellite. The PACE sensor basically utilizes a method of a top hat electrostatic analyzer with angular scanning deflectors at the entrance and toroidal electrodes inside. The FOV (Field Of View) is electrically scanned between $\pm 45^\circ$ around the center of the FOV, that is $45^\circ$ inclined from the axis of symmetry. With two electron sensors and two ion sensors that are installed on the +Z (ESA-S1 and IMA: looking down the lunar surface) and -Z (ESA-S2 and IEA: looking against the lunar surface) panels of the spacecraft, the three-dimensional plasma distribution function is observed. This author has participated deeply in development, calibration, and data evaluation of the PACE sensors.

IMA, one of the PACE sensors, had observed Moon-originating ions for more than 1 year until June 11, 2009. We have analyzed the mass-identified ion observation data of IMA by using the laboratory calibration data and numerical simulation. When the Moon is in the solar-wind, generated Moon-originating ions are accelerated and transported by an interplanetary electric field $E = -V_{sw} \times B_{sw}$. At 100km altitude, these pick-up ions are presumably not fully accelerated and have the energy below several hundred electron volts under typical solar-wind condition. The observed ion energy represents the acceleration path length, and the energy distribution reflects the altitude distribution of the lunar exosphere. We analyzed the Moon-originating ion data observed by IMA, and separated the surface-originated ion with the exospheric ions making use of the solar-wind motional electric field.

The SELENE ion measurement in Earth's magnetosphere indicated that PSD is the major generation process of the SBE. In the absence of plasma effects on the source process, ion species of $H^+$, $He^{++}$, $He^+$, $C^+$, $O^+$, $Na^+$, $K^+$ and $Ar^+$ are definitively identified. The ion fluxes were higher when the solar zenith angle was smaller, which is consistent with the idea that the solar photon driven processes dominates in supplying exospheric components. These Moon-originating ions are transported by the electrostatic potential difference between the Moon and the satellite.

The lunar atmosphere composition experiment (LACE), a part of the Apollo science program, set the lunar surface and accomplished firm detection of argon and helium during the lunar night. The LACE argon data measured at the Apollo 17 showed the asymmetry between the sunset and sunrise. However the ground-based observations of the lunar alkali exosphere have never showed these dawn-dusk asymmetry. We calculated the daily variation of the pick-up ion flux, and obtained the SSE (selenocentric solar ecliptic) longitude dependence of the K ion flux. The SSE longitude dependence shows the distinguished dawn-dusk asymmetry. We modeled this asymmetry by the photon-derived source including the depletion of the surface source. In this study, we will report the confinement of the atmospheric source based on the results of several data analysis and discuss the structure and the dynamics of the lunar SBE.