RELATIONSHIP BETWEEN THE GEOTAIL SPACECRAFT POTENTIAL AND THE ELECTRON DENSITY IN THE NEAR TAIL REGIONS

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ABSTRACT
The spacecraft potential has been used to derive the electron density surrounding the spacecraft in the magnetosphere and solar wind. The previous studies have examined the relationship between the spacecraft potential and the electron density in the distant tail regions and obtained an empirical formula to show their relation. However the electron density obtained by the empirical formula is often overestimated in the near tail regions with high electron temperature. In this study, we investigate the relationship between the Geotail spacecraft potential and the electron density/temperature in the near tail regions during the period from November 1994 to February 1997, and improve the empirical formula considering the electron temperature. Then we discuss on the investigation of distribution of low energy plasma in the near tail region by comparing the electron density obtained by the improved empirical formula with that measured by the low-energy particle instrument onboard the Geotail spacecraft.

Introduction
Spacecraft in sunlight is generally charged to a positive potential relative to the ambient plasma in the solar wind and almost all the regions of the magnetosphere because of the photoelectron emission from the spacecraft conductive surface. Several studies have shown the relation between the spacecraft potential and the electron number density surrounding the spacecraft [Pedersen et al., 1984; Schmidt et al., 1987; and Escoubet et al., 1997]. Escoubet et al. [1997] have determined this relationship for potentials up to 30 V. The present authors have investigated the relation between the Geotail spacecraft potential and electron number density derived from the plasma waves during the period from September 1992 to December 1995 and an empirical formula was obtained to show their relation in which the range of potentials was from a few volts up to 80 V [Ishisaka et al., 2001]. However, the electron density estimated from the empirical formula given by Ishisaka et al. [2001] is overestimated in the near magneto-tail regions where the electron temperature is high. Therefore cannot obtain the electron density using the spacecraft potential and the empirical formula in the region with the high electron temperature.
In this study we investigate the correlation between the spacecraft potential of the Geotail spacecraft and electron density derived from the plasma waves in the near magneto-tail region, where the electron temperature is high relatively, during the period from November 1994 to February 1997. Then we obtain an approximate formula to show their relation considering the electron temperature. Using the new approximate formula, we can obtain the electron density in the region where the characteristic frequency of plasma waves to indicate the electron plasma frequency cannot be seen clearly. Therefore we can obtain the electron density in the almost all the regions of the magnetosphere, except for the high-density plasmasphere.

Relationship between spacecraft potential and electron density in the near tail region

The spacecraft potential of Geotail spacecraft is measured by the single probe system, which is one of the subsystems of the electric field detector (EFD) [Tsuruda et al., 1994]. The single probe system measures the difference of potential between the spacecraft and the spherical probe at the top of long wire boom. The probe potential can be set nearly equal to the ambient plasma potential by feeding a proper bias current to the probe. Therefore the voltage measured by the single probe system is approximately equal to the spacecraft potential for ambient plasma.

We examine the relationship between the spacecraft potential ($V_{s/c}$) and the electron density (N_e) in the near tail regions. The electron density is estimated by the characteristic frequency of plasma waves, such as the lower cutoff frequency of continuum radiation (CR) and the center frequency of Langmuir waves, which are observed by t he plasma wave instrument (PWI) [Matsumoto et al., 1994]. Therefore we investigate the $V_{s/c} - N_e$ characteristics in the region where the lower cutoff frequency of CR or the center frequency of Langmuir waves can be clearly seen during the period from November 1994 to February 1997. Since we do not always see the lower cutoff frequency of CR clearly, we do not sample it in the case of weak CR. We also cannot use data during the periods when an ion emitter turns on because the ion emitter keeps the spacecraft potential at values relatively close to the ambient plasma potential.

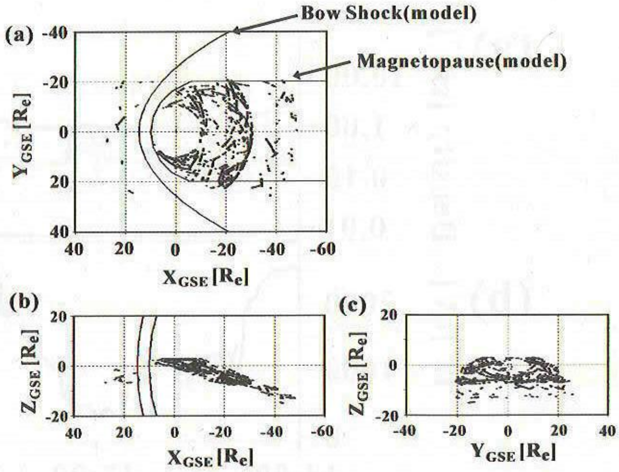

Figure 1. Geotail orbit plotted on the GSE coordinates using this study during the period from November 1994 to February 1997.

Figure 1 shows the Geotail orbits at that time when we actually sampled for valid data during the period from November 1994 to February 1997. The top panel (a) shows the X-Y plane and two bottom panels, (b) and (c), show the X-Z plane and Y-Z plane in the geocentric solar ecliptic (GSE) coordinate system. The Figure 2 shows the $V_{s/c} - N_e$ relation for the electron temperature measured by the measured by the low energy particle instrument (LEP) onboard Geotail spacecraft [Mukai et al., 1994]. The horizontal and vertical axes show the spacecraft

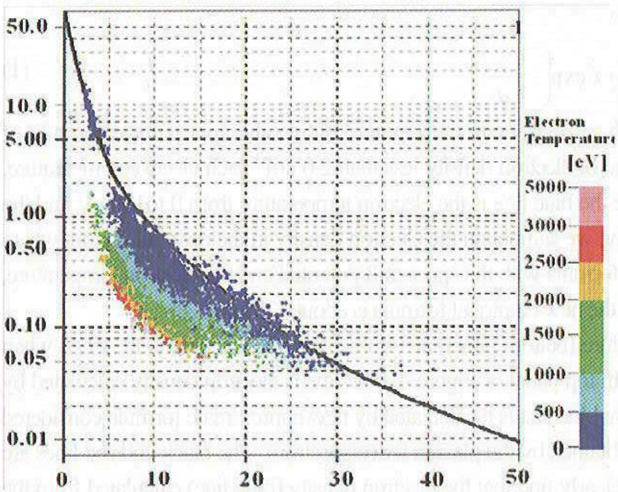

Figure 2. Characteristic of relationship between the spacecraft potential and the electron density in the near tail regions.

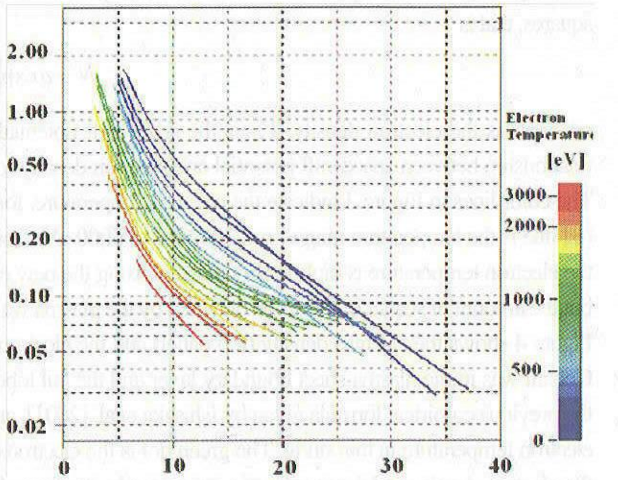

Figure 3. Approximate formula of relationship between the spacecraft potential and the electron density each electron temperature.

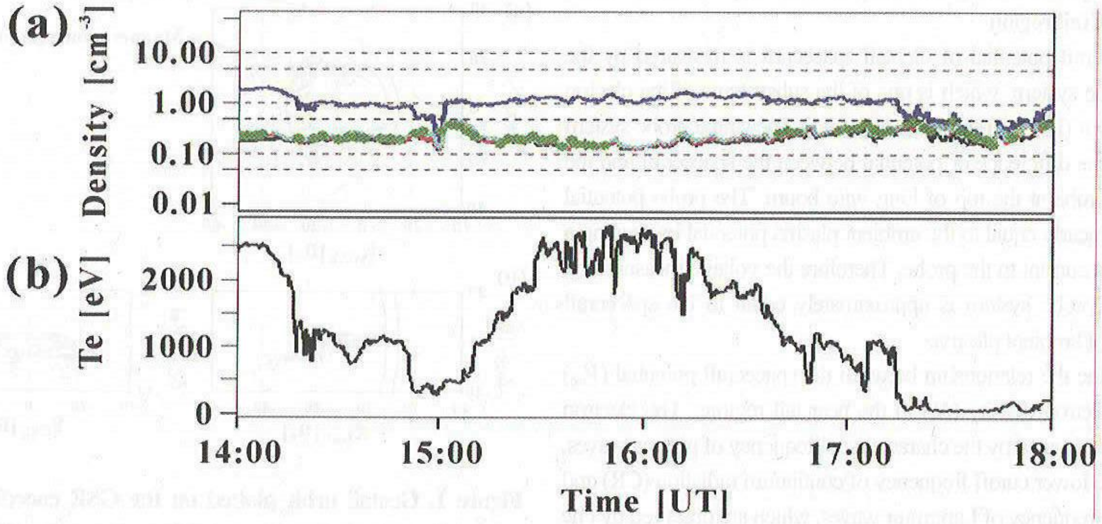

Figure 4. Electron density and electron temperature observed by the Geotail spacecraft at 14:00 – 18:00 UT, 30 January, 1997. (a)top panel : Electron density calculated by spacecraft potential with new empirical formula, measured by the LEP and estimated by the PWI, respectively. (b) bottom pane : Electron temperature measured by the LEP.

potential and the electron density, respectively. In Figure 2, the blue dot indicate the data when the electron temperature less than 500 eV, and the pink dot indicate the data when the electron temperature is from 3000 eV to 5000 eV. The solid line in the Figure 2 shows the empirical formula given by Ishisaka et al. [2001]. This empirical formula is used for obtaining the electron density in the solar wind and the distant magneto-tail region. Therefore the dot observed in the solar wind where the electron density is more than 2.0 cm^{-3} fit the solid line in the Figure 2. However we can clearly find that the Vs/c – Ne relation depends on the electron temperature. The best function to the data in the range of electron temperature 100 eV each is represented by an approximate formula with two exponentials using the method of least squares, that is

$$N = a\exp\left(-\frac{V_{s/c}}{b}\right) + c\exp\left(-\frac{V_{s/c}}{d}\right) \qquad (1)$$

where N is the electron density, $V_{s/c}$ is the spacecraft potential and a, b, c, d are constant. Figure 3 shows the approximate formula of relationship between spacecraft potential and electron density in the range of electron density less than 2.0 cm^{-3} each electron temperature. The color lines in Figure 3 indicate the electron temperature, for example the blue line is the electron temperature from 0 to100 eV and the red line is the temperature range from 3000 eV to 5000 eV. Consequently, we can obtain the electron density in the near tail region, where the electron temperature is high for hot plasma, using the new empirical formula with the spacecraft potential and the electron temperature, but the amount of scatter of the value obtained by the plasma waves from the new empirical formula is about ±20%.

Figure 4 shows the electron density (top panel) and the electron temperature (bottom panel) at 14:00 – 18:00 UT, January 30, 1997, when Geotail was in the plasma sheet boundary layer and the tail lobe region. In top panel of Figure 4, blue line is electron density calculated by the previous empirical formula given by Ishisaka et al. [2001], and the light blue line is it calculated by new approximate formula considered electron temperature in this study. The green dot is the electron density obtained by the plasma wave spectrum. The black and red lines are the electron density and the ion density, respectively. In Figure4 we can clearly find that the electron density (blue line) calculated from the previous empirical formula is overestimated in the region where the electron temperature is higher than 500 eV. The electron density (light blue line) calculated from the new approximation formula considering the electron temperature in this study agrees with the electron density estimated by the plasma waves and observed by the LEP at the all time, although the electron temperature is high. Therefore we can obtain the electron density using the spacecraft potential and the electron temperature in the near tail regions.

Conclusion

We have investigated the characteristic of the relationship between the spacecraft potential measured by the EFD and the electron density estimated from the plasma waves in the near tail region. Then the data have been fit to an approximate formula that gives electron density as a function of spacecraft potential each amount of electron temperature. The approximate formula is applied to obtain the electron density in the solar wind and almost all the regions of the magnetosphere including the near tail region with high electron temperature. Therefore we can obtain the electron density in the near magneto-tail region. In particular we can also obtain the electron density in the region where the electron plasma frequency cannot be clearly seen, such as the plasma sheet boundary layer and the boundary layer between the bowshock and the magnetosphere.

In future work we will investigate the low-energy plasma quantitatively in the bowshock and magnetosphere. The investigation of low-energy plasmas below 32eV using data obtained by the Geotail was reported by Matsui et al. [1999]. They used the electron density determined by the plasma waves and data obtained by the LEP onboard Geotail spacecraft. The electron density estimated by the plasma waves includes cold components that were not measured by the particle detectors. On the other hand, from the LEP data, the energy range of ions was between 32 eV and 39 keV while the energy range of electrons was between 60 eV and 38 keV. The density (N) of low-energy plasma is estimated from $N = N_{pwi} - N_{LEP}$, where N_{pwi} is the total density acquired from plasma waves and N_{LEP} is the partial density acquired from the LEP. However the electron density cannot be estimated by the plasma waves when the characteristic frequency indicated the electron plasma frequency cannot be clearly seen. We will substitute the electron density obtained by the spacecraft potential using the new approximate formula for that estimated by the plasma waves. The electron density obtained from the spacecraft potential is affected by the electrons in a wider energy range. Then we try to investigate the low-energy plasma in the dawn-side region where it is very difficult to obtain the electron plasma frequency because the electron cyclotron harmonic waves merge with the lower cut-off frequency of the continuum radiation. We will then attempt to construct a model that can explain the region supplied by the ionosphere plasma directly. With the completion of these models, we will be able to understand the details of the existence of low-energy plasma in the outer and inner magnetosphere.

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