Statistical study on warm plasma in the magnetotail based on two-component fits of distribution functions

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A large number of observations reported two distinct plasma populations with different temperatures in the Earth's magnetotail: 1-10 keV for the hotter component and <1 keV for the colder. It is well accepted that plasma of solar wind origin can enter into the magnetosphere due to tailward convection of magnetic field lines that were reconnected at the dayside magnetopause, or due to instabilities or waves that develop on the dawn and dusk flanks. Cold plasma of ionospheric origin can be also transported into the plasma sheet predominantly along the field lines. Such cold plasma can be then heated/accelerated to 1 keV or higher. The dominant transport region(s) and heating mechanism(s) are, however, not well understood. This study investigates global characteristics of warm (10-1000 eV) plasma populations observed in the magnetotail in order to better understand transport regions of solar wind and ionospheric plasma.

We use data from plasma observations made by the Hot Plasma Composition Analyzer (HPCA) on board the Magnetospheric Multiscale (MMS) spacecraft. HPCA measures ions with energies of a few eV to ~40 keV with the determination of ion mass. We perform a one-component Maxwellian fit and a two-component Maxwellian fit to a distribution function of the omni-directional proton flux during intervals of slow flow speed (<~70 km/s). The best fit provides density and temperature of one-component Maxwellian plasma or density and temperature for each component of two-component Maxwellian plasma. This study is focused most on the colder (hotter) component of the two-component plasma, which we term a cold (normal) population. We apply this analysis and categorization to HPCA proton data obtained for a period of May 1 to August 31 of Year 2017. MMS dwelled in the magnetotail for the period, and HPCA data are available in the regions of 6 Re < r < 24 Re.

We examine dependence of density and temperature on plasma beta, which is the ratio of plasma thermal pressure to the magnetic pressure and thus represents the distance from the current sheet. The normal population shows clear positive correlations of density and temperature to plasma beta. This indicates adiabatic heating of lobe plasma transported toward the central plasma sheet. The cold population, on the other hand, does not show clear correlations. It is separated into three different types. Type 1 is characterized by positive correlations of density to plasma beta, similar to the normal population. Density is between 0.01 and 0.1 cm^{-3} at a beta range of 0.001 to 0.01, and increases to ~1 cm^{-3} at beta of >0.1. We confirm that the relation between density and temperature is well explained by adiabatic heating with the specific heat ratio of 5/3. Type 2 is seen only in the high beta (>0.1) regions, with density of ~0.01 cm^{-3}. Type 3 can be identified by a different relation between density and beta; density is between 0.01 and 1.0 with the highest occurrence frequency at 0.1 cm^{-3}, and temperature is a few 10s to 100s eV. Spatial distributions of each type show that Types 1 and 2 are observed at the radial distance of >10 Re. Type 1 shows no clear dawn-dusk asymmetry of occurrence frequency or average temperature, while Type 2 is more frequently observed on the dusk and dawn sides than around midnight. Type 3 occupies the region closer to 10 Re and is also observed at the radial distance of 10-20 Re with lower occurrence.

We interpret that Type 1 is dominated by plasma of solar wind origin transported over the polar regions, through the lobe toward the plasma sheet. Type 2 is likely solar wind plasma that enters through the flank

magnetopauses. Type 3 is of ionospheric origin, presumably from nightside auroral regions. We suggest that the north-south component of magnetospheric convection over the polar cap becomes dominant at the radial distance of 10 Re or further. Instabilities or waves that allow solar wind plasma to enter the plasma sheet are likely to sufficiently develop on the night side (i.e., $X < 0$).

Keywords: Entry of solar wind plasma, Supply of ionospheric plasma , plasma mixing, magnetospheric cold plasma

