Terrestrial molecular ion outflow observed at the Moon

M. O. Fillingim, A. R. Poppe, J. S. Halekas, J. Raeder, V. Angelopoulos, and I Dandouras

Recently, Poppe et al. [2016] reported on Acceleration, Reconnection, Turbulence, and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS) spacecraft observations of multiple instances of outflowing molecular ionospheric ions at lunar distances in the terrestrial magnetotail. The heavy ion fluxes are observed during geomagnetically disturbed times and consist of mainly molecular species (N_2^+, NO^+, and O_2^+, approximately masses 28 – 32 amu) on the order of 10^5 – 10^6 cm^{-2} s^{-1} at nearly identical velocities as concurrently present protons. By performing backwards particle tracing in time-dependent electromagnetic fields from the magnetohydrodynamic Open Global Geospace Circulation Model (OpenGGCM) of the terrestrial magnetosphere, they showed that the ions escape the inner magnetosphere through magnetopause shadowing near noon and are subsequently accelerated down-tail to lunar distances. This type of circulation, energization, and transport within Earth's magnetosphere appears fundamentally different from that seen at planets with much smaller, induced magnetospheres (i.e., Venus and Mars). Here, we expand upon previous observations by investigating the spatial distribution of the molecular ion observations in the magnetotail and by correlating times of molecular ion observations with geomagnetic activity and solar wind drivers. While the outflow mechanism is unknown, these observations reveal a direct pathway for plasma from the ionosphere to be lost to the deep magnetotail. While the heavy molecular densities are low (about 0.01 cm^{-3}, two to three orders of magnitude lower than the ambient proton density), loss of molecular ions over geologic time may have significantly affected the terrestrial atmosphere, particularly early in Earth's history when solar driving is thought to have been more intense.