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Observations of electron vortex magnetic holes and related wave-particle interactions in the turbulent magnetosheath

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Magnetic hole is characterized by a magnetic depression, a density peak, a total electron temperature increase (with a parallel temperature decrease but a perpendicular temperature increase), and strong currents carried by the electrons. The current has a dip in the core region of the magnetic hole and a peak in the outer region of the magnetic hole. There is an enhancement in the perpendicular electron fluxes at 90° pitch angles inside the magnetic hole, implying that the electrons are trapped within it. The variations of the electron velocity components Vem and Ven suggest that an electron vortex is formed by trapping electrons inside the magnetic hole in the circular cross-section. These observations demonstrate the existence of a new type of coherent structures behaving as an electron vortex magnetic hole in turbulent space plasmas as predicted by recent kinetic simulations. We perform a statistically study using high time solution data from the MMS mission. The magnetic holes with short duration (i.e. < 0.5 s) have their cross section smaller than the ion gyro-radius. Superposed epoch analysis of all events reveals that an increase in the electron density and total temperature, significantly increase (resp. decrease) the electron perpendicular (resp. parallel) temperature, and an electron vortex inside the holes. Electron fluxes at $\sim 90°$ pitch angles with selective energies increase in the KSMHs, are trapped inside KSMHs and form the electron vortex due to their collective motion. All these features are consistent with the electron vortex magnetic holes obtained in 2D and 3D particle-in-cell simulations, indicating that the observed the magnetic holes seem to be best explained as electron vortex magnetic holes. It is furthermore shown that the magnetic holes are likely to heat and accelerate the electrons. We also investigate the coupling between whistler waves and electron vortex magnetic holes. These whistler waves can be locally generated inside electron vortex magnetic holes by electron temperature anisotropic instability.