Electron- and proton-scale nested magnetic cavities: Manifestation of kinetic theta-pinches equilibrium in space plasmas

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Magnetic cavities, sometimes referred to as magnetic holes, are ubiquitous in space and astrophysical plasmas characterized by localized regions with depressed magnetic field strength, strongly anisotropic particle distributions, and enhanced plasma pressure. Typical cavity sizes range from fluid to ion and sub-ion kinetic scales, with recent observations also identifying nested cavities that may indicate cross-scale energy cascades. Although heavily investigated in space, magnetic cavities have analogs in laboratory plasmas, the classical theta-pinches. Here, we develop an equilibrium solution of the Vlasov-Maxwell equations in cylindrical coordinates (in similar format to theta-pinches models), to reconstruct the cross-scale profiles of magnetic cavities observed by the four-spacecraft MMS mission. The kinetic model uses input parameters derived from single-spacecraft measurements to successfully reproduce signatures of magnetic cavities from all observing spacecraft. The reconstructed profiles demonstrate that near the electron-scale cavity boundary, the decoupled electron and proton motions generate a radial electric field that contributes to electron vortex formation that has been previously attributed mostly to diamagnetic effects. At larger scales, the diminishing electric field implies that diamagnetic motion is solely responsible for proton vortices.