Recent observations of magnetic cavities: from MHD to kinetic scale

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Magnetic cavities, also termed magnetic holes, dips or depression structures, have an observable magnetic field decrease in a short time span and have been widely observed in the solar wind plasmas, comet magnetospheres, terrestrial/planetary magnetosheaths, magnetospheric cusps and magnetotail plasmas since 1970s. In early observations, the structures were found in MHD scale, from tens to thousands of $\rho_i$ (proton gyroradius) with corresponding temporal scales from seconds to tens of minutes. Later, kinetic scale magnetic cavities were detected in the earth’s magnetotail and magnetosheath, with size less than $\rho_i$ and sometimes close to several $\rho_e$ (electron gyroradius) and often associated with a significant electron vortex around the structure. Surprisingly, it has been found that such a small structure contains an abundance of phenomena, including different kinds of ion and electron distributions, electron or ion vortices, various types of waves, and even particle acceleration and declarations. In this presentation, we will show our recent observations of magnetic cavities from MHD scale to kinetic scale in the solar wind, magnetosheath, cusp and magnetotail. In the magnetosheath, downstream of the bow shock, the mirror mode instability can generate magnetic dip and peak trains. Using data from the new NASA satellite constellation MMS, we have found that electrons exhibit a new ‘donut’ shaped distribution function related to particle deceleration processes. Using boundary normal and velocity determination techniques, we found that MHD scale magnetic cavity structures can expand or shrink, and they can enter the cusp regions along with the entry plasmas. In the turbulent magnetosheath and quiet magnetotail, we have observed kinetic scale magnetic cavity structures with scales comparable or less than one $\rho_i$. An EMHD model and other theories will also be introduced and compared. We found that in the sheath the electron scale magnetic cavity has a circular cross section and it is a magnetic bottle in 3-D. We have also found that these structures shrink due to increases in the surrounding magnetic field, and this shrinkage of the small scale magnetic cavity can induce an electric field that accelerates the electrons to a significantly higher energy. Qualitatively distinct from other acceleration mechanisms, this process indicates a new type of non-adiabatic acceleration, and has been confirmed by the observed electron distribution function and test particle simulations. This discovery in space physics also has implications for understanding energy conversion in astrophysical plasmas, the origin of cosmic high-energy particles and plasma turbulence.

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