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Electron Holes in phase-space: what they are and why they matter

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Plasma electron holes are soliton-like electric potential structures sustained self-consistently by a deficit of phase-space density on trapped orbits. They are a class of Bernstein Green and Kruskal (BGK)-mode phase-space vortices, long studied in basic analytic and computational theory and observed in some experiments. Recently it has become clear from space-craft observations that isolated potential structures with the character of electron holes constitute an important component of space-plasma turbulence. Modern computational simulations of collisionless plasmas also often observe electron holes to form as a nonlinear consequence of kinetic electron instabilities. This tutorial will explain the basic theory of electron hole structure, trace the development of the understanding of electron holes, and survey some of the observational evidence for their significance. It was found early on that unmagnetized multidimensional simulations of electron two-stream instabilities do not show the long lived holes that appear in one dimension. Deliberately-created 1-D slab holes in multiple dimensions experience a transverse instability unless the guiding magnetic field is strong enough. Analysis has yet to identify unequivocally the instability mechanism and threshold; but it can show that spherically symmetric holes in 3-D without magnetic field are essentially impossible. Recent simulations have studied holes' formation, self-acceleration, merging, splitting, and growth. Analytic understanding of many of these phenomena is gained from the kinematics of the hole regarded as a coherent entity, accounting for the plasma momentum changes it induces, and especially the interaction with the ions. Electron holes can travel at up to approximately the electron thermal speed, but not slower (relative to ions) than several times the ion acoustic speed. Some notable current research questions will be described.