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Vlasov simulations of electron hole dynamics in inhomogeneous magnetic field

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Electron holes (EHs) or phase space vortices are solitary electrostatic waves existing due to electrons trapped within EH electrostatic potential. Since the first direct observation [1], EHs have been widely observed in the Earth's magnetosphere: in reconnecting current sheets [2], injection fronts [3], auroral region [4], and many other space plasma systems. EHs have typical spatial scales up to tens of Debye lengths, electric field amplitudes up to hundreds of mV/m and propagate along magnetic field lines with velocities of about electron thermal velocity [5]. The role of EHs in energy dissipation and supporting of large-scale potential drops is under active investigation.

The accurate interpretation of spacecraft observations requires understanding of EH evolution in inhomogeneous plasma. The critical role of plasma density gradients in EH evolution was demonstrated in [6] using PIC simulations. Interestingly, up to date no studies have addressed a role of magnetic field gradients in EH evolution. In this report, we use 1.5D gyrokinetic Vlasov code to demonstrate the critical role of magnetic field gradients in EH dynamics. We show that EHs propagating into stronger (weaker) magnetic field are decelerated (accelerated) with deceleration (acceleration) rate dependent on the magnetic field gradient. Remarkably, the reflection points of decelerating EHs are independent of the average magnetic field gradient in the system and depend only on the EH parameters. EHs are decelerated (accelerated) faster than would follow from the "quasi-particle" concept assuming that EH is decelerated (accelerated) entirely due to the mirror force acting on electrons trapped within EH. We demonstrate that EH propagation in inhomogeneous magnetic fields results in development of a net potential drop along an EH, which depends on the magnetic field gradient. The revealed features will be helpful for interpreting spacecraft observations and results of advanced particle simulations. In particular, our simulations suggest that slow EHs (which generation is usually attributed to the Buneman instability) can arise due to slowing down of fast EH generated by electron-beam instability. The estimate of the potential drop along EHs allow to estimate the parallel potential drop provided by EHs in a particular plasma system.

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