Reconciling Eulerian and Lagrangian views of electron energization

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Abstract

The Lagrangian guiding center model (LGCM) has been used extensively to study electron energization during magnetic reconnection. Simulations and spacecraft observations applying the LGCM have shown that Fermi and betatron acceleration can be important for accelerating electrons to high energies. Recently, an Eulerian fluid model (EFM) of electron energization was proposed by TenBarge et al. (2024), which they demonstrated using Vlasov-Maxwell simulations of magnetic reconnection. Their results showed that the Lagrangian and Eulerian energization models predict different energization rates both locally and globally (meaning simulation domain integrated).

In this work, we use particle-in-cell simulations of reconnection to expand on the work by TenBarge et al. (2024) to understand why the two models differ, and what actually happens to the electrons when the two models predict qualitatively different energization. We show that, for low guide fields, local and global errors can arise in the LGCM due to the erroneous assumption of magnetic moment conservation for electrons that the LGCM relies on. At higher guide fields such that electrons remain magnetized, we find a global agreement between the two models. Local deviations between the two models remain, however, and we show that they are due to the difference between the Eulerian and Lagrangian descriptions. The LGCM describes the work done on the specific electrons currently inside a given grid element, while the EFM describes the evolution of the net electron energy within the grid element. The latter is affected by the flux of energy through the element, while the former is not. This explains why the two models can give seemingly contradictory results while both being valid. We conclude that both energization models are valid, but that one should be careful when selecting which model to use and when interpreting the results.

References

TenBarge, J. M., Juno, J., & Howes, G. G. (2024). Electron energization in reconnection: Eulerian vs Lagrangian perspectives. Physics of Plasmas, 31(2).

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