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Electron scale magnetic holes generation driven by Whistler-to-Bernstein mode conversion in fully kinetic plasma turbulence

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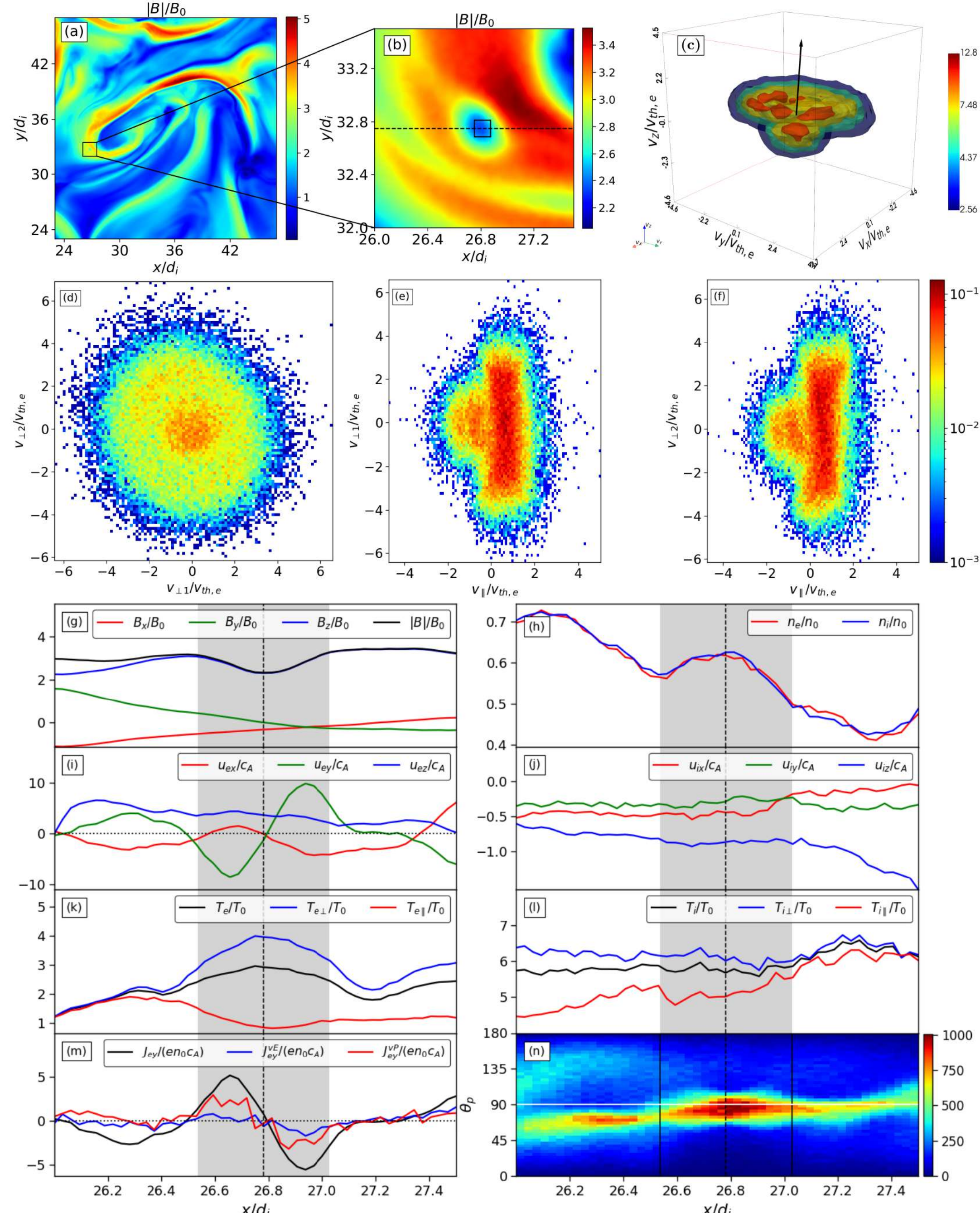
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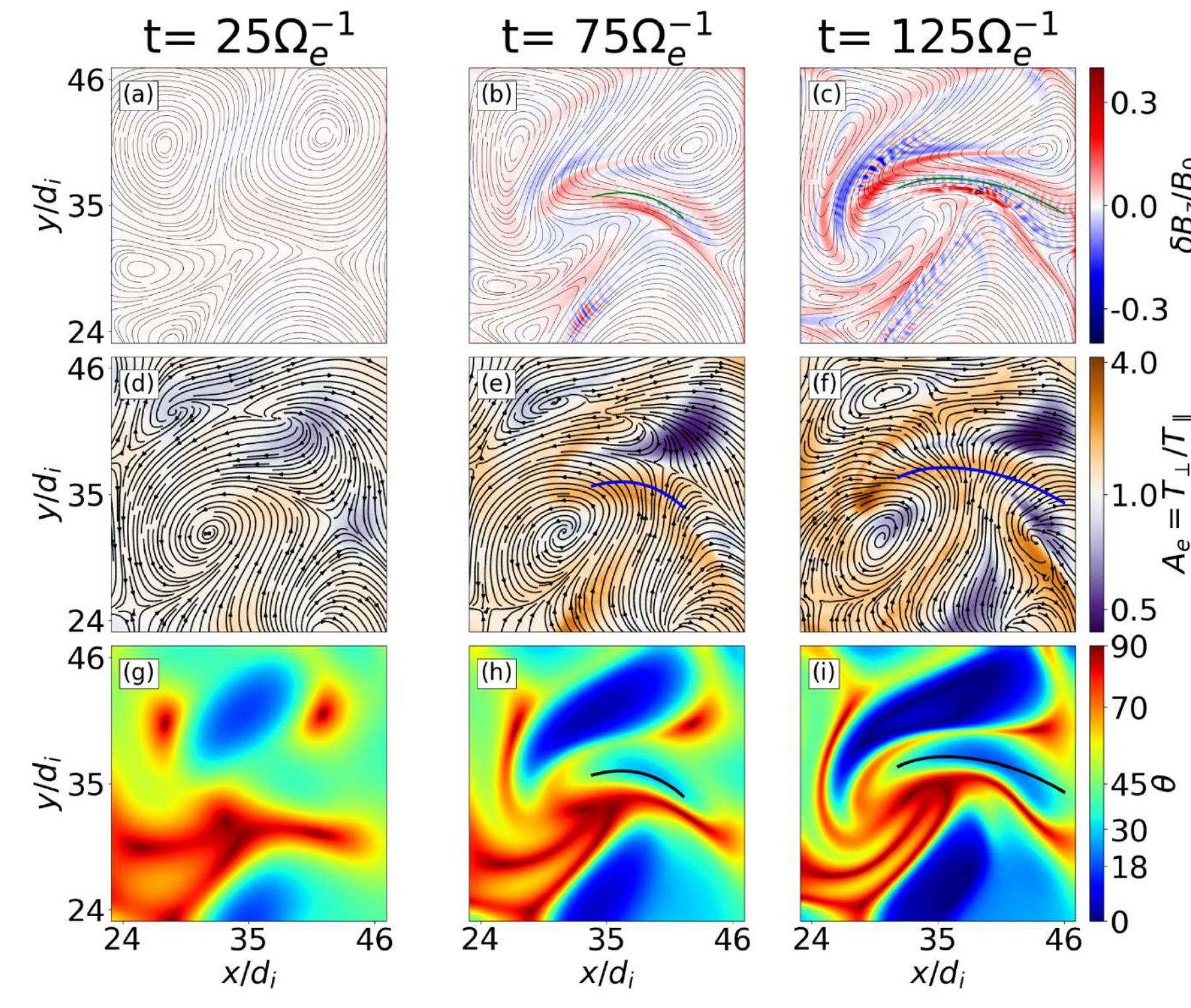
Abstract

Magnetic holes (MHs) are coherent structures characterized by a strong and localized magnetic field amplitude dip, commonly observed in the heliosphere. These structures come in different sizes, from magnetohydrodynamic to kinetic scales. Subion scale MHs are usually sustained by an electron current vortex and exhibit a strong electron temperature anisotropy, with higher temperatures perpendicular to the background magnetic field. Magnetospheric Multiscale observations (MMS) have revealed electron scale MHs to be ubiquitous in the turbulent Earth's magnetosheath and the solar wind, potentially playing an important role in the energy cascade and dissipation. Despite abundant observations, the origin of electron scale MHs is still unclear and debated. In this work, we use fully kinetic simulations to investigate the role of plasma turbulence in generating electron scale MHs. We find that the turbulence spontaneously produces electron scale MHs via the following mechanism: first, large-scale turbulent velocity shears produce regions with high electron temperature anisotropy; these localized regions become unstable, generating oblique electron scale whistler waves; as they propagate over the inhomogeneous turbulent background, whistler fluctuations develop an electrostatic component, turning into Bernstein-like modes; the strong electrostatic fluctuations produce current filaments that merge into an electron scale current vortex; the resulting electron vortex locally reduces the magnetic field amplitude, finally evolving into an electron scale MH. We show that MHs generated by this mechanism have properties consistent with MMS and nontrivial kinetic features with a "mushroom" shaped electron velocity distribution function. Our results have potential implications for understanding the formation and occurrence of electron scale MHs in astrophysical turbulent and space environments, such as the Earth's magnetosheath and the solar wind.

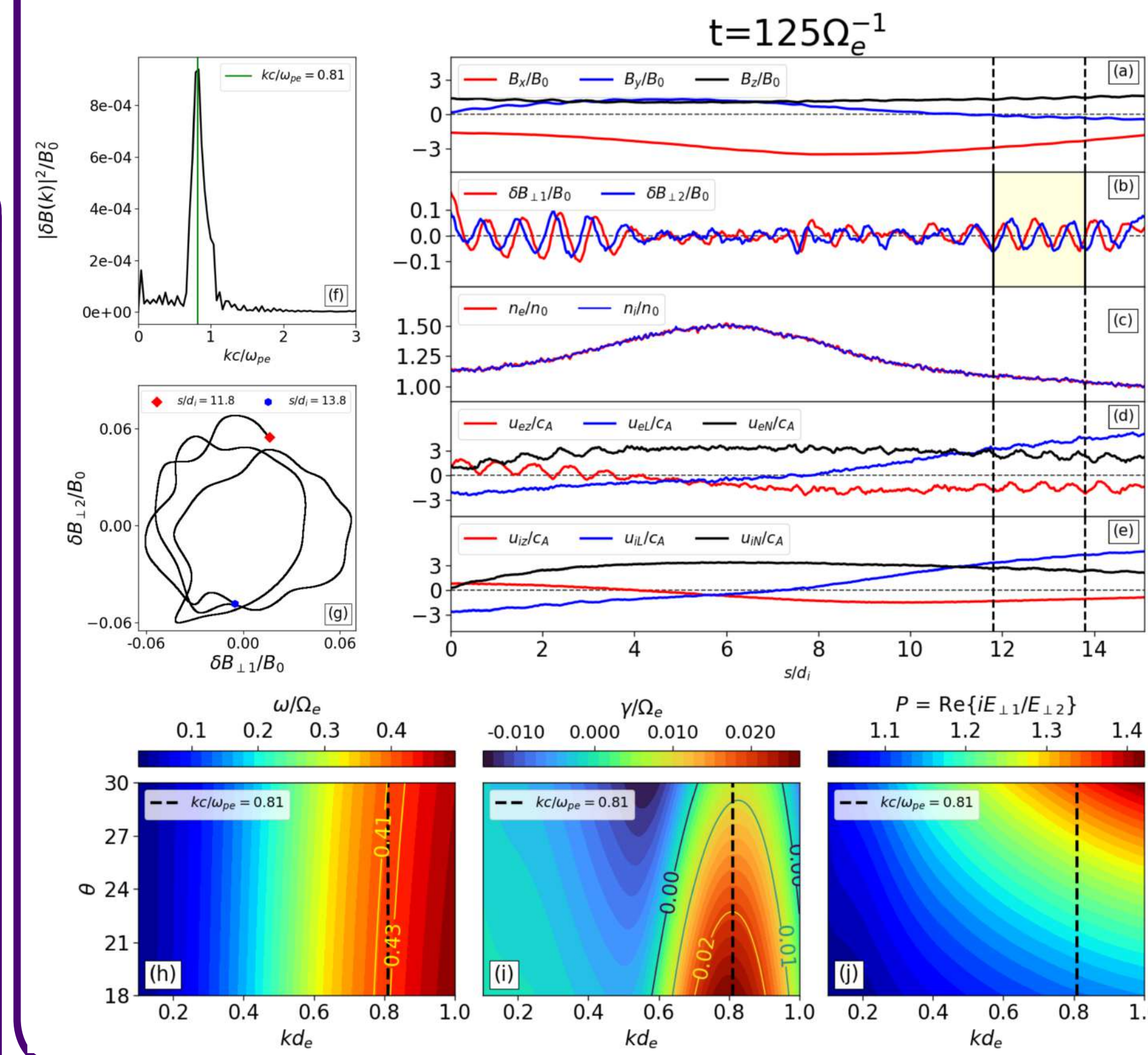
I. Fully developed Electron Scale Magnetic Hole



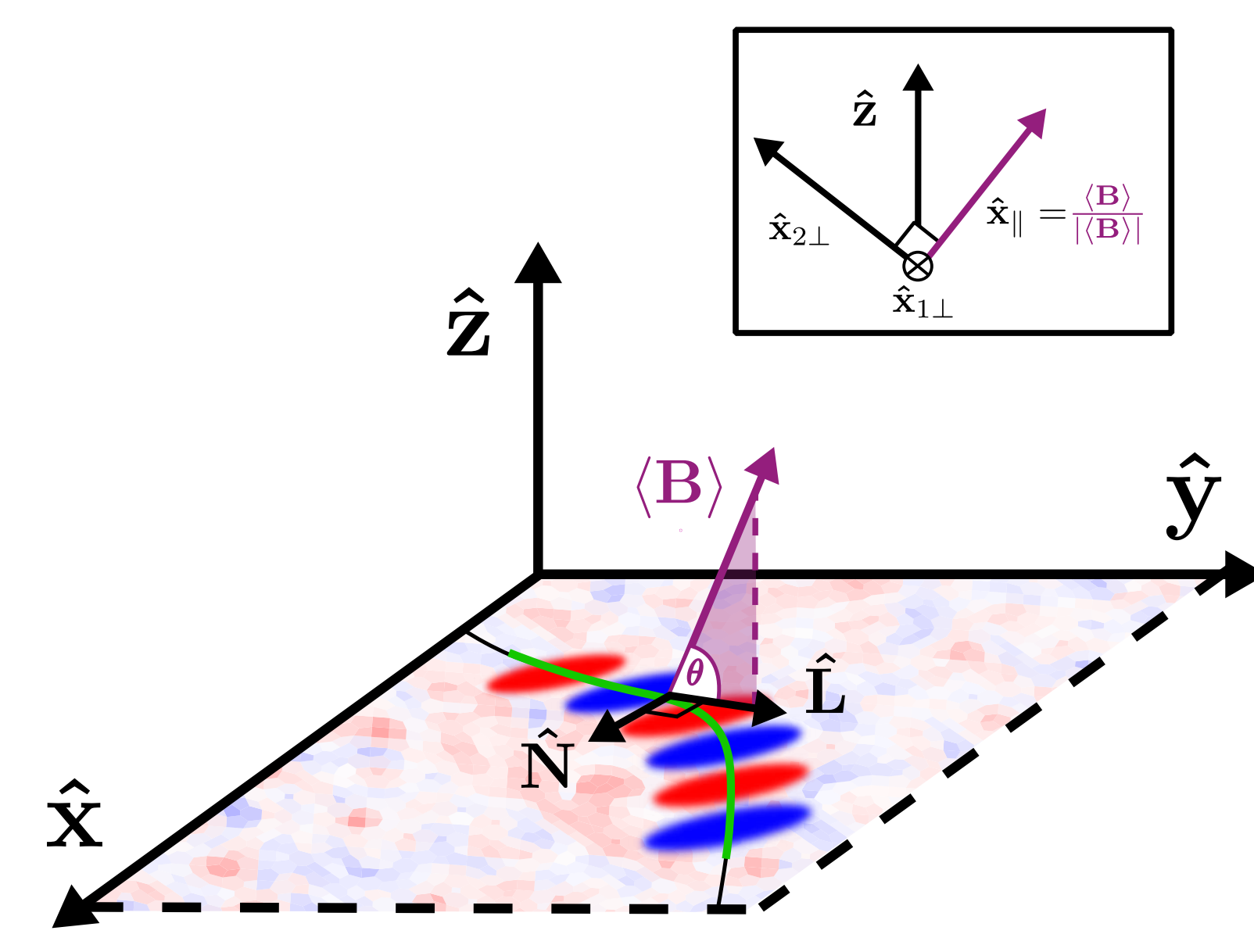
II. Whistler wave generation



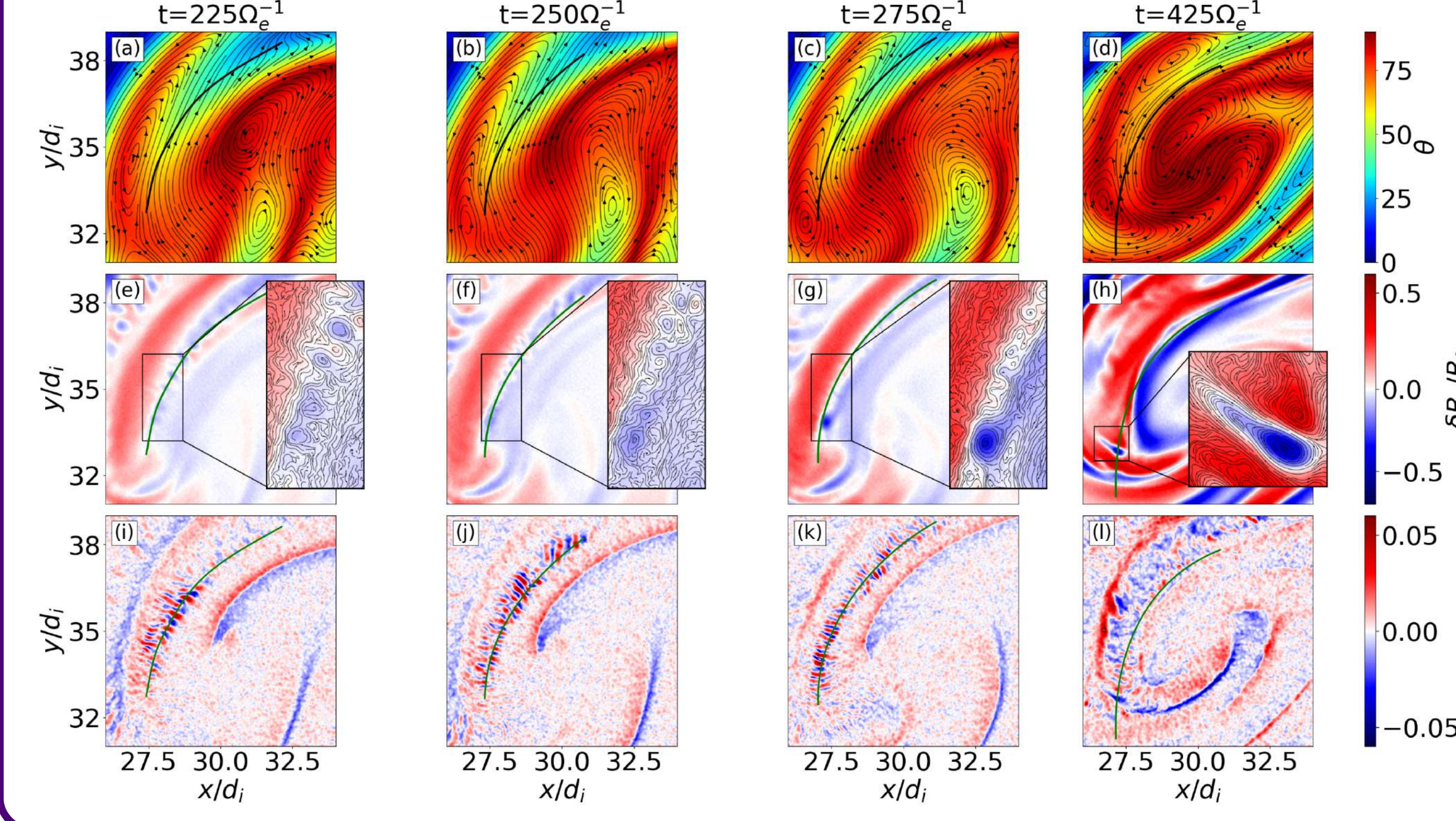
III. Whistler wave properties and Linear Solver



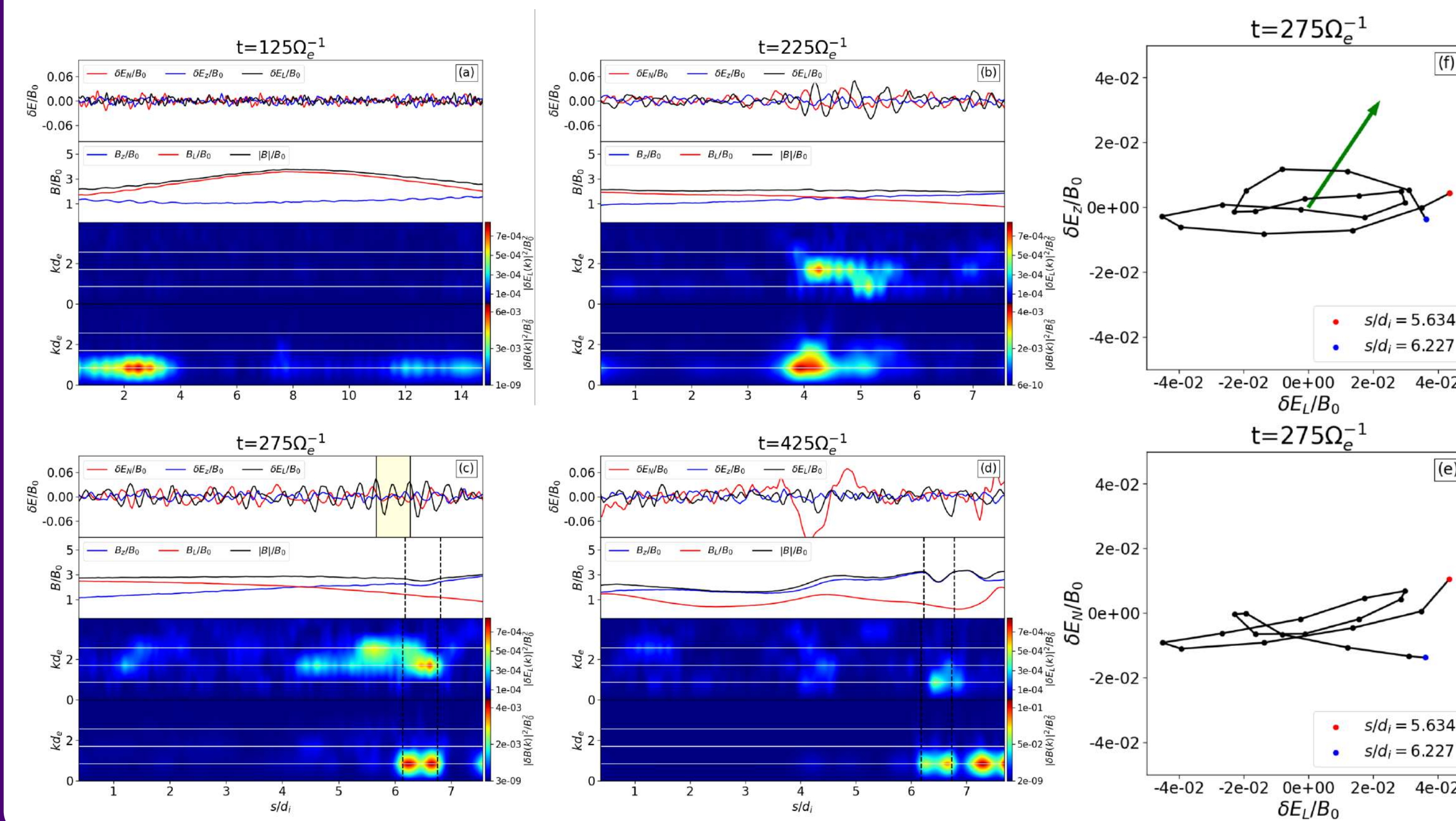
System of coordinates



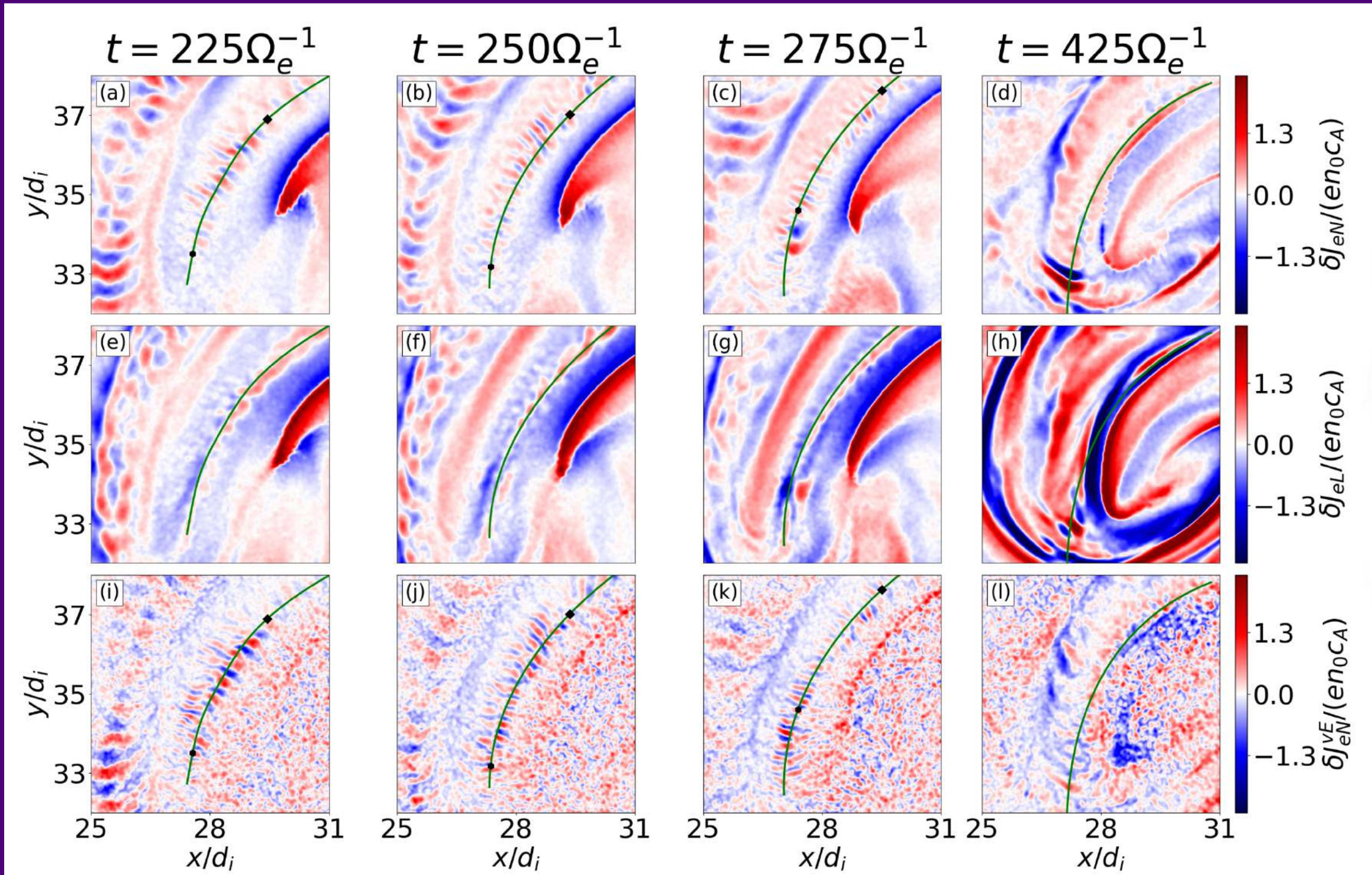
IV. Longitudinal electric field fluctuations and Vortex merging



V. Whistler-to-Bernstein mode conversion



VI. Vortex formation due to currents induced by the quasi-electrostatic Bernstein-like mode



VII. E x B drift current and current density correlation

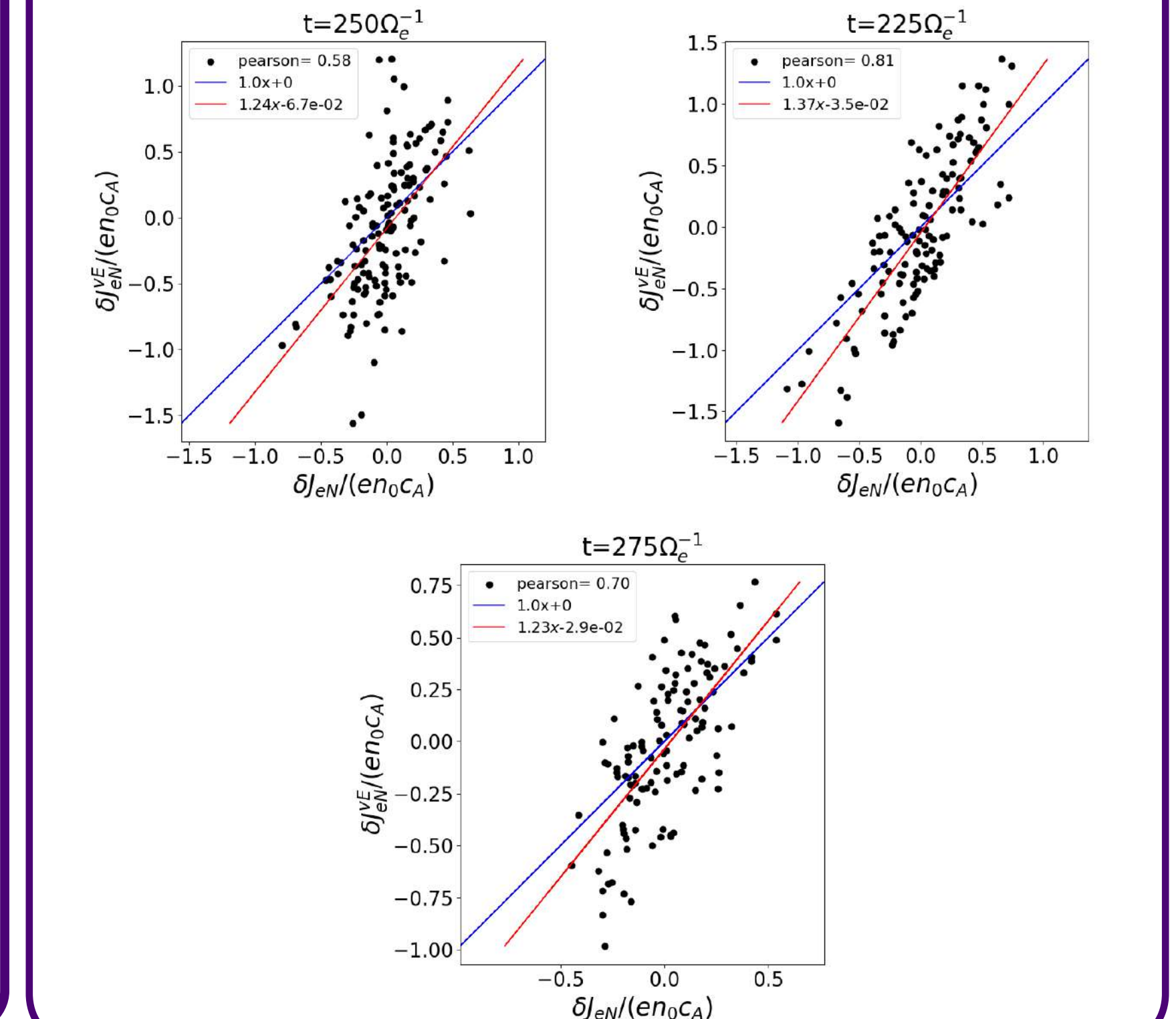
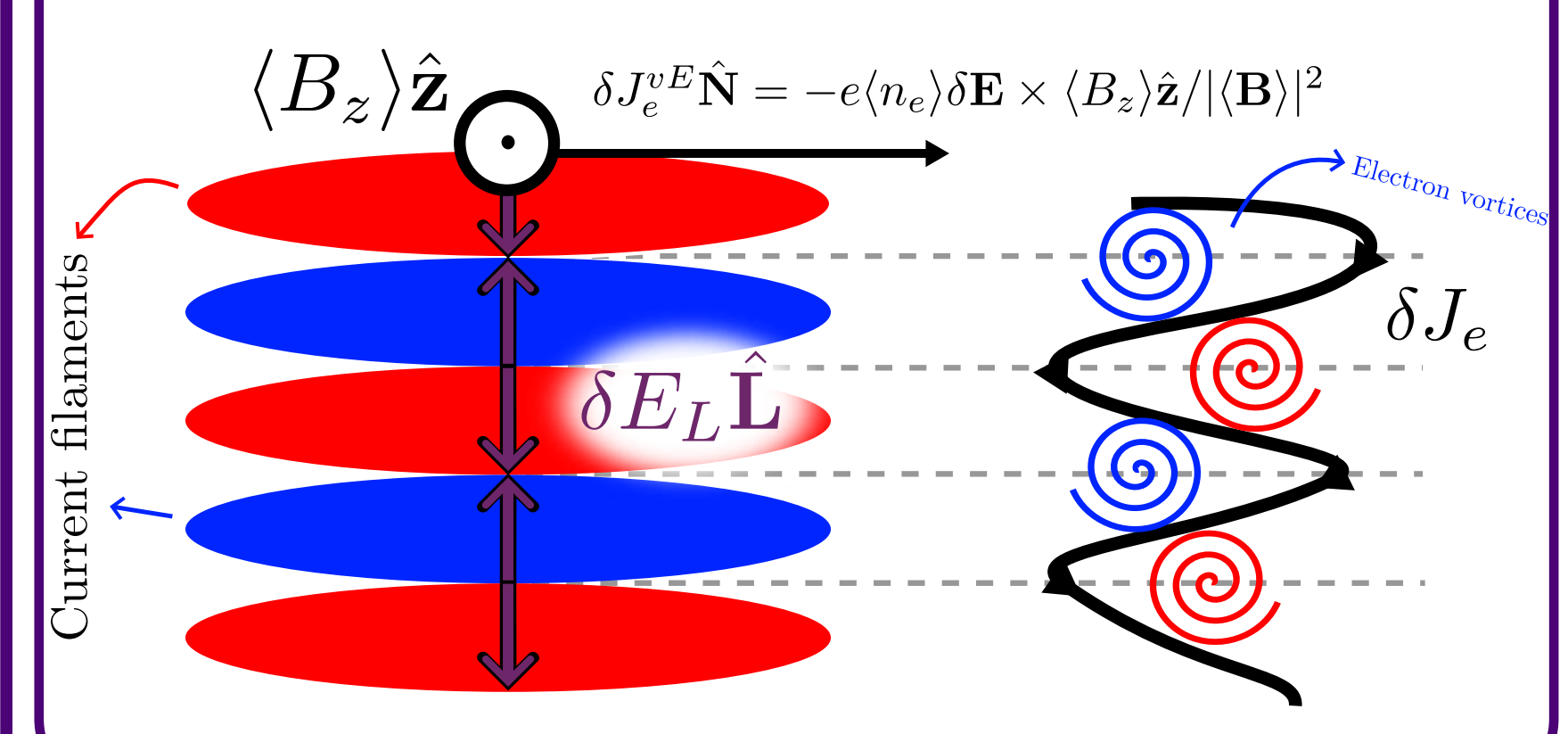


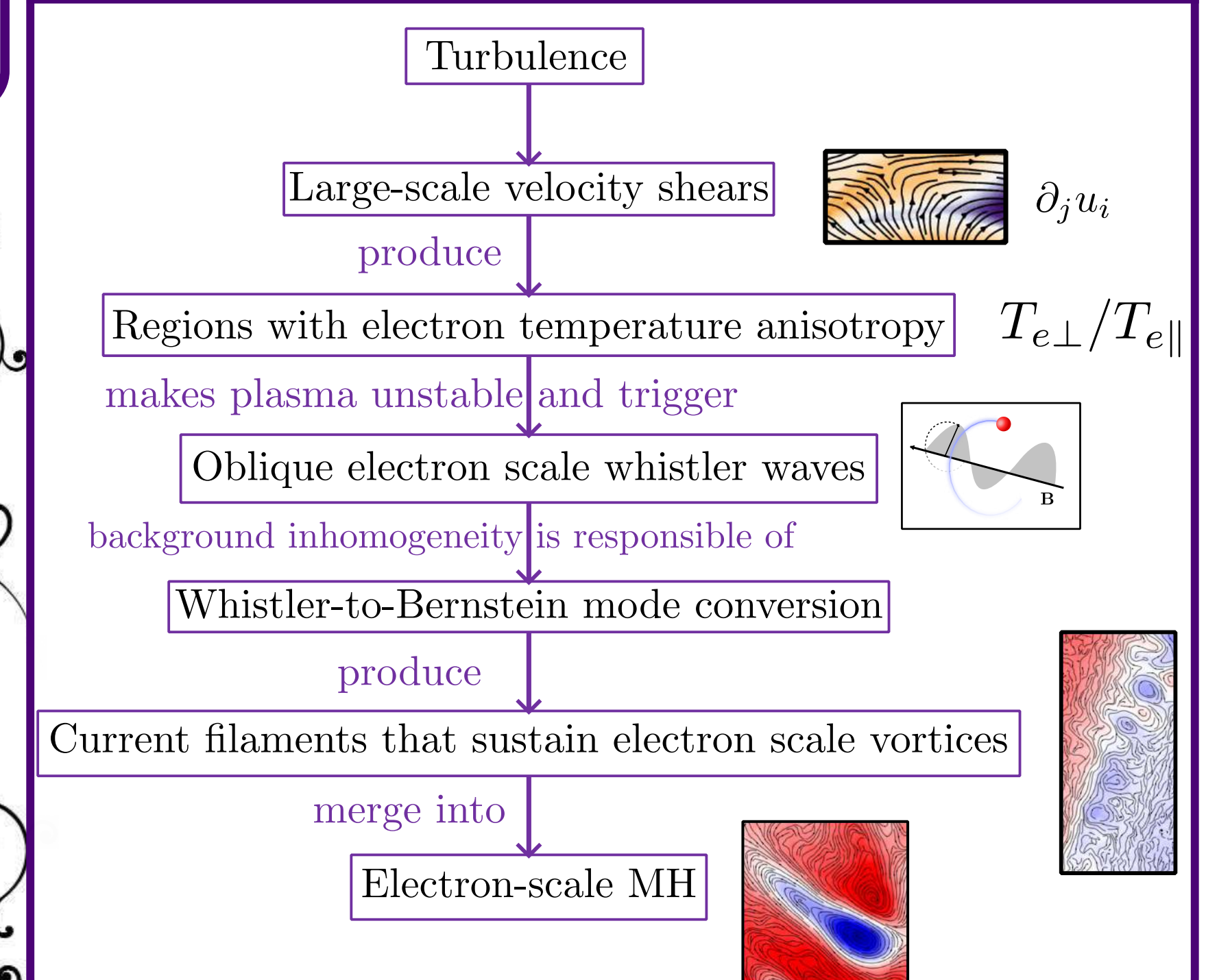
Illustration of electron scale vortices formation



Summary and conclusions

■ We have shown that turbulent-driven dynamics are capable of generating electron scale magnetic holes.
■ We have highlighted the importance of non-linear wave processes and scale interactions in the generation of magnetic holes.

Summary of the mechanism for the electron scale MH formation



References

[1] Espinoza-Troni, J., Arrò, G., F. A. Asenjo and P. S. Moya. Electron scale magnetic holes generation driven by Whistler-to-Bernstein mode conversion in fully kinetic plasma turbulence, accepted for publication. arXiv:https://doi.org/10.48550/arXiv.2501.09651, 2025