Enhanced Reconnection in Three-Dimensional Electron-only Reconnection

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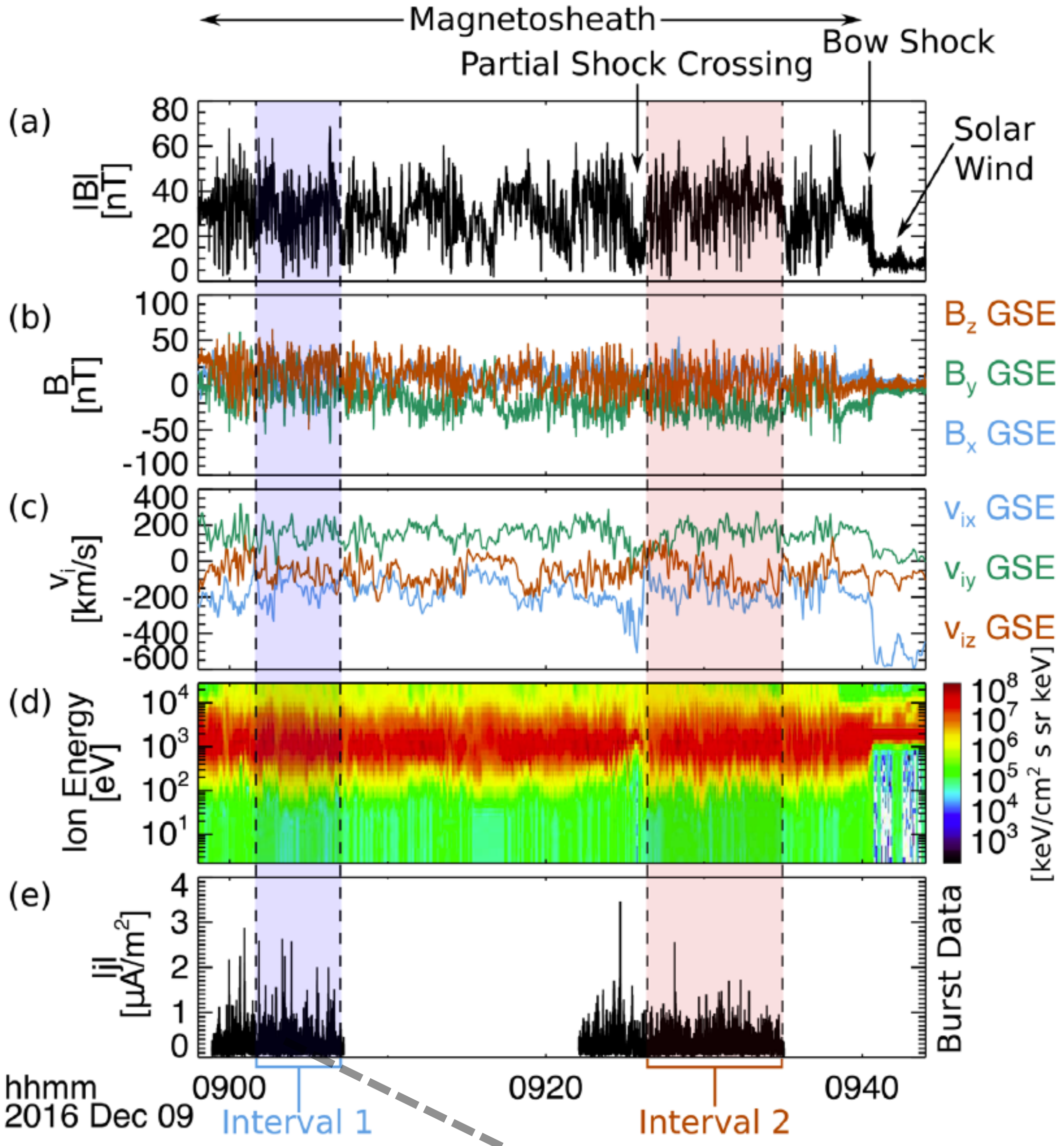
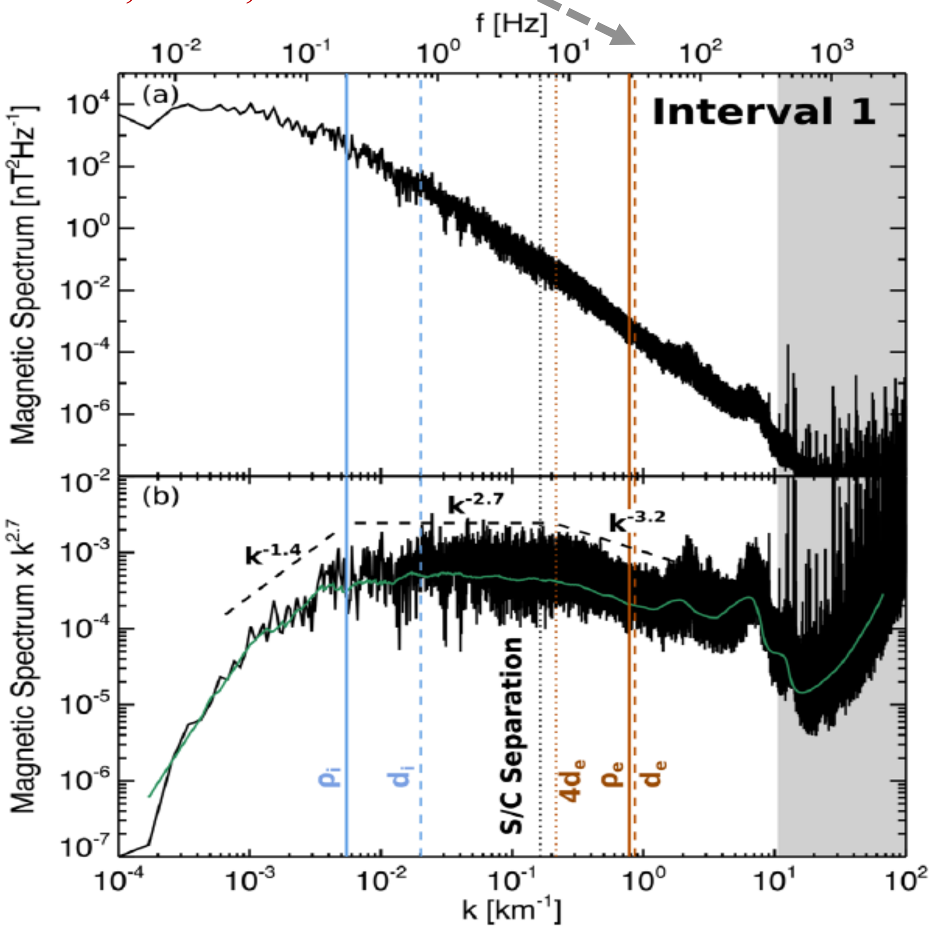
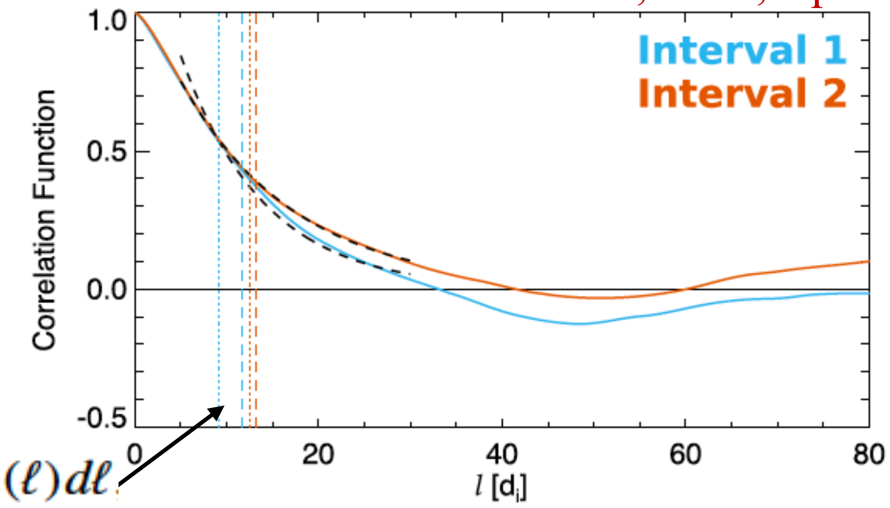
Stawarz et al., 2019, ApJ



Phan et al., 2018, Nature event included in this interval



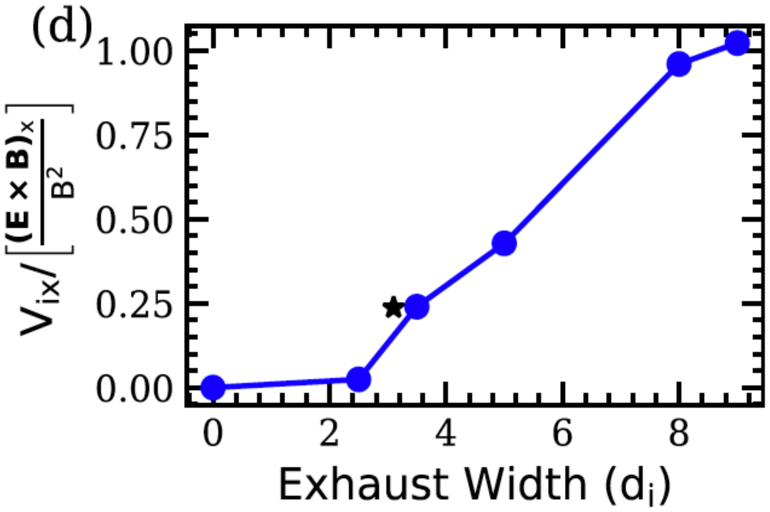
Stawarz et al., 2019, ApJ



$$\lambda_c \equiv \int_0^\infty R(\ell)d\ell$$

The correlation length, roughly speaking, is the size of the biggest eddies in the turbulent flow

Pyakurel et al., 2019, PoP



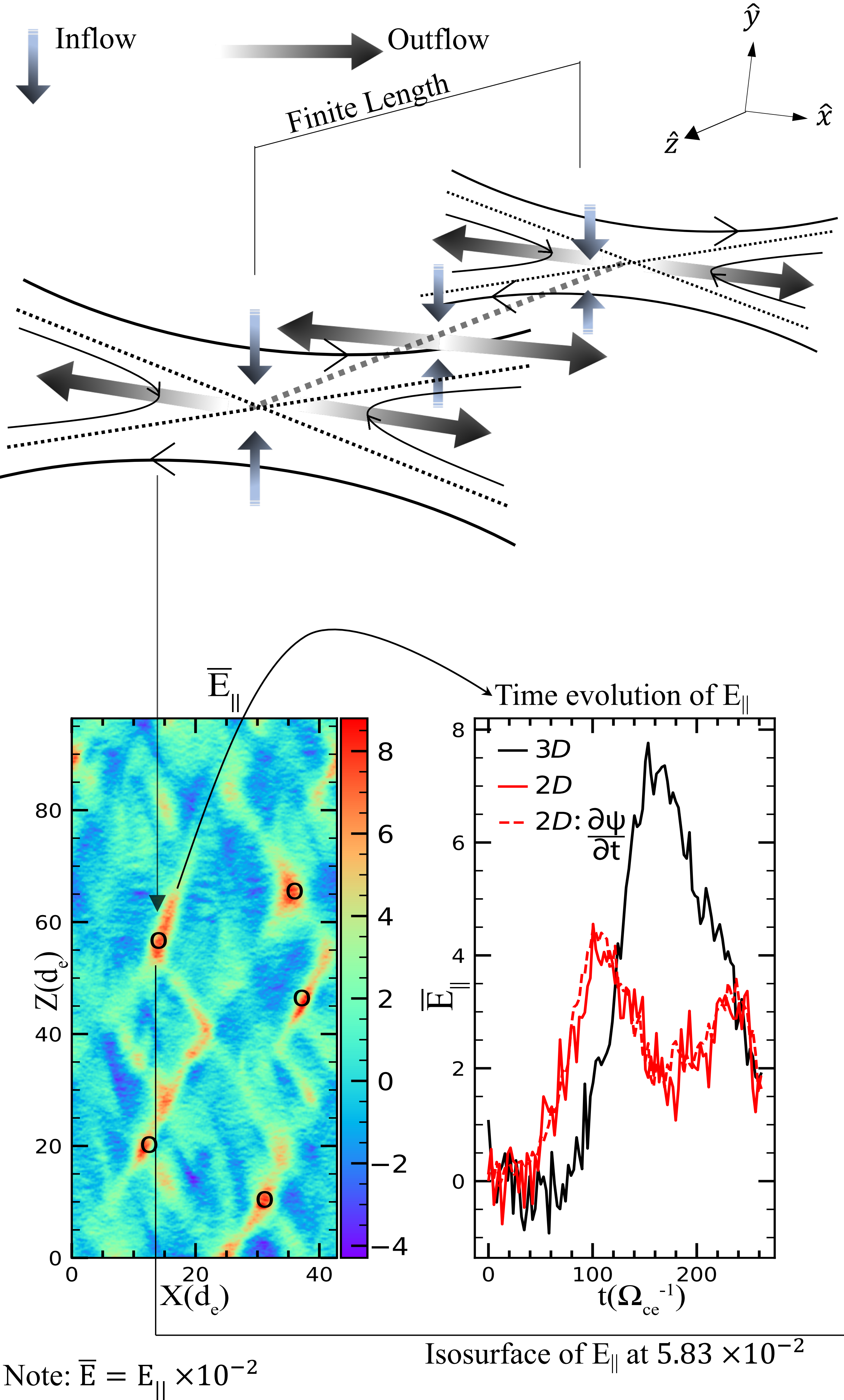
1. Correlation length scales of few d_i
2. The current sheet structures are spatially limited in all dimensions
3. Current sheet structures are highly 3D in nature
4. Small scale (few electron inertial length, d_e) finite length X-lines are likely generated

Other examples

Observations:
1. Gingell et al., 2019, GRL
2. Wang et al., 2019, GRL

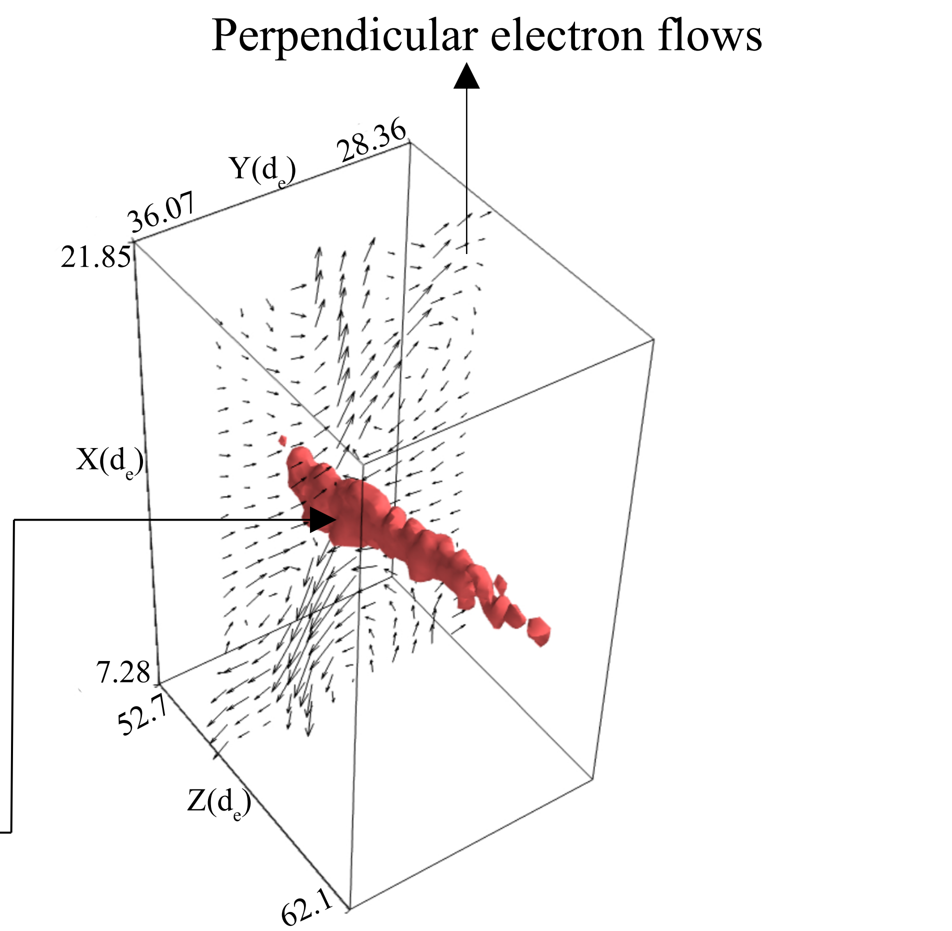
Simulations/Theory:
1. Vega et al., 2020, APJL
2. Bessho et al., GRL, 2019

Finite Length Electron-Only Reconnection

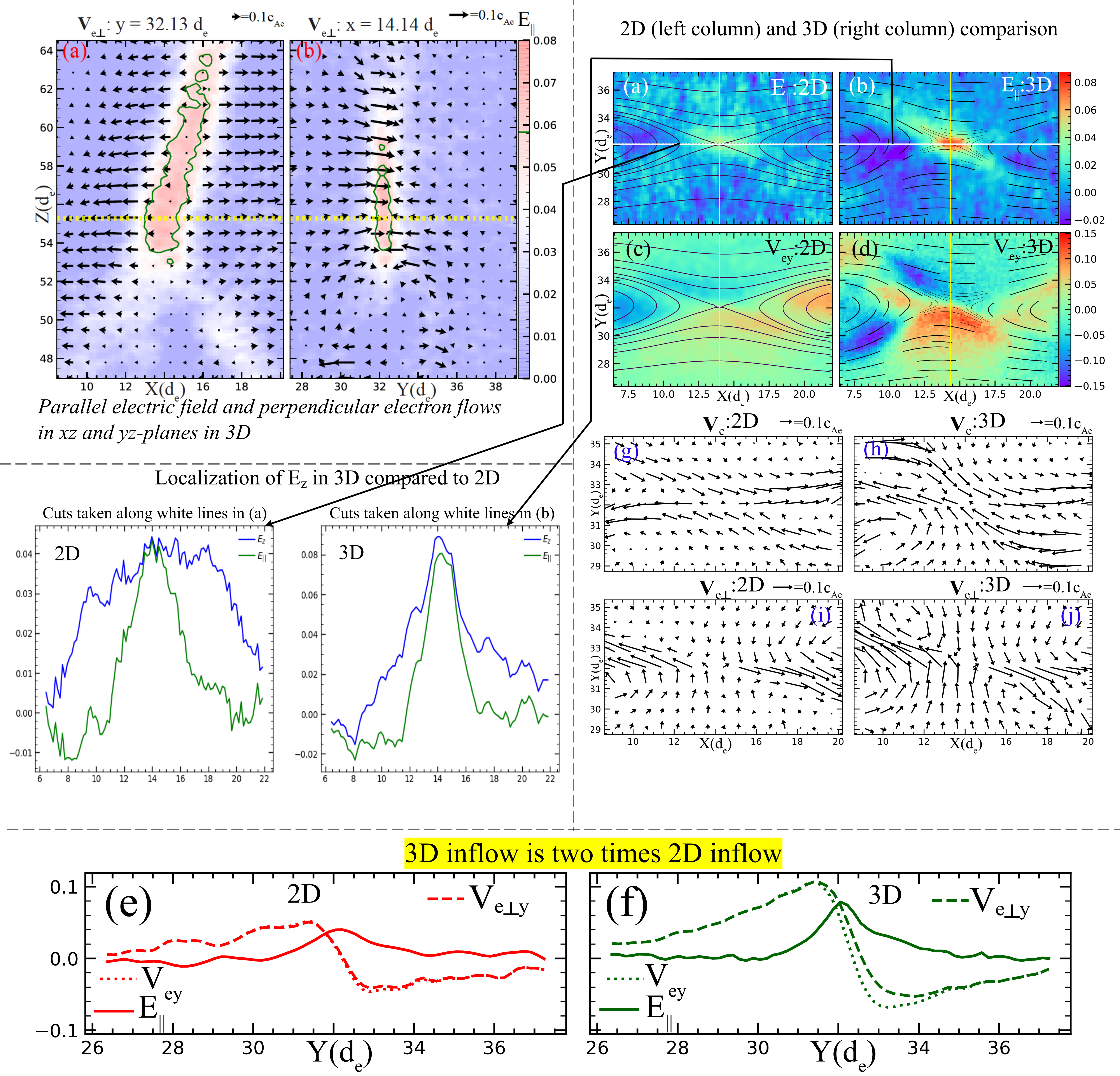


Particle-In-Cell (PIC) Simulation Setup

1. Force-free initial condition with real mass ratio and $\beta \sim 3$.
2. No initial perturbation, reconnection onset due to PIC noise.
3. Real mass ratio $m_i/m_e = 1836$
4. Guide field asymptotes to the reconnecting field of 1.0 outside the current sheet
5. The initial current sheet consists solely of electron current with ions as a neutralizing background
6. All figures normalized to electron units: Lengths to electron inertial length (d_e), time to inverse electron cyclotron frequency (Ω_{ce}^{-1}), velocity to electron Alfvén speed (c_{Ae})



Finite Length Electron-Only Reconnection



3D Control Volume Analysis

Mass flux through each face is given by

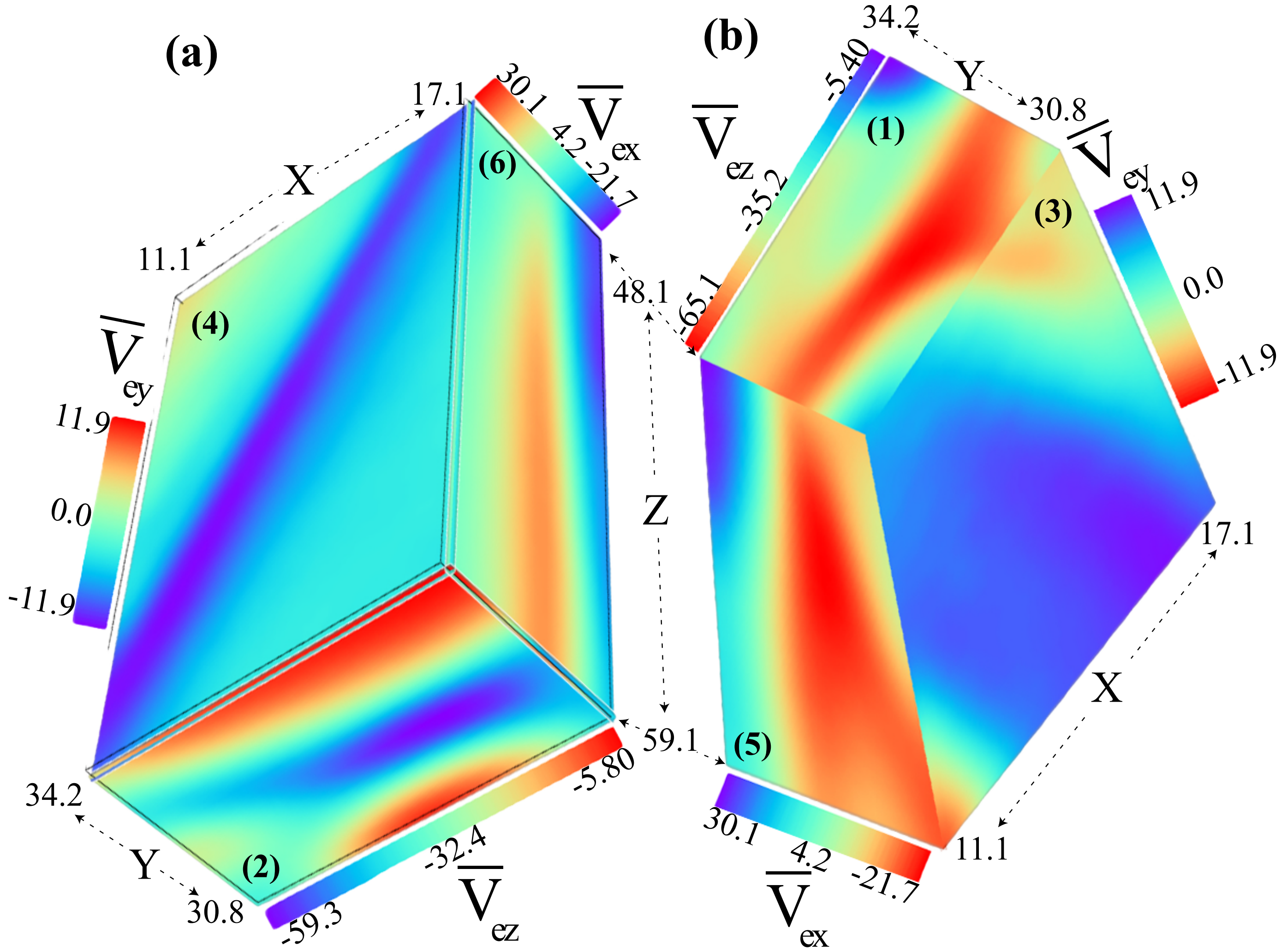
$$\Phi_i = \sum_{l,m} [\mathbf{V}_{e,i}(l,m) \cdot \hat{n}]\, \Delta^2$$

where i is one of the six faces, $\hat{n}$ is a unit vector pointing out of the face and (l,m) indexes are the grid point locations of the face.

$|\Phi_1 + \Phi_2|$: difference in the mass flux in the z-direction

$|\Phi_3 + \Phi_4|$: total mass flux in the y-direction

$|\Phi_5 + \Phi_6|$: total mass flux in the x-direction



Flow into and out of the diffusion region, where $\overline{\mathbf{V}} = \mathbf{V}_e \times 10^2$. Panels (a) and (b) show normal flow through each of the six faces of the diffusion region, which are numbered. For example, normal flow through face 2 at $z = 59.13$ is given by V_{ez}

We find, $|\Phi_1 + \Phi_2| = |\Phi_5 + \Phi_6|$ & $|\Phi_1 + \Phi_2| + |\Phi_5 + \Phi_6| = |\Phi_3 + \Phi_4|$

Remarks

1. Electron flow feature of finite length X-line in electron-only reconnection is different than 2D.
2. We find that the larger reconnection rate in 3D is due to the flow of mass out of the boundary of the diffusion region (along the z-direction).
3. A control volume analysis of the diffusion region reveals that in 3D, the net mass flux along z is equal to the net mass flux along x. This increased outward mass flux allows an inflow velocity twice what is present in 2D, leading to twice the reconnection rate.
4. Is there an upper bound on the reconnection rate in 3D electron-only reconnection?