Role of Cold Ions in Parallel Current and Hall Field Enhancement along Separatrices in Magnetopause Reconnection

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Abstract

Motivation

- Most particles do not pass directly through the electron or ion diffusion regions, but are instead accelerated along the separatrices and within the reconnection outflow jets.
- Cold ions can modify the Hall physics, current systems, and energy conversion during reconnection (André et al., 2016; Dargent et al. 2017; Toledoet al., 2018; Baraka et al. 2015).
- However, their influence on parallel current and separatrix displacement remains unclear.
- Here, we compare two 2D fully kinetic PIC simulations (SMILEI): with and without cold ions.

Simulation setup

- The simulation box size is (320,128) d_i
- Density ratio $n_r = n_{sh}/n_{sp} = 3$
- Mass ratio = $m_i/m_e = 25$
- Magnetic field ratio: $B_{sh}/B_{sp} = 0.5$

- Run Standard
  - No cold ions
- Run IC
  - Density and temperature ratios in the magnetosphere : $n_h/n_c = 0.5$ and $T_h/T_c = 500$.

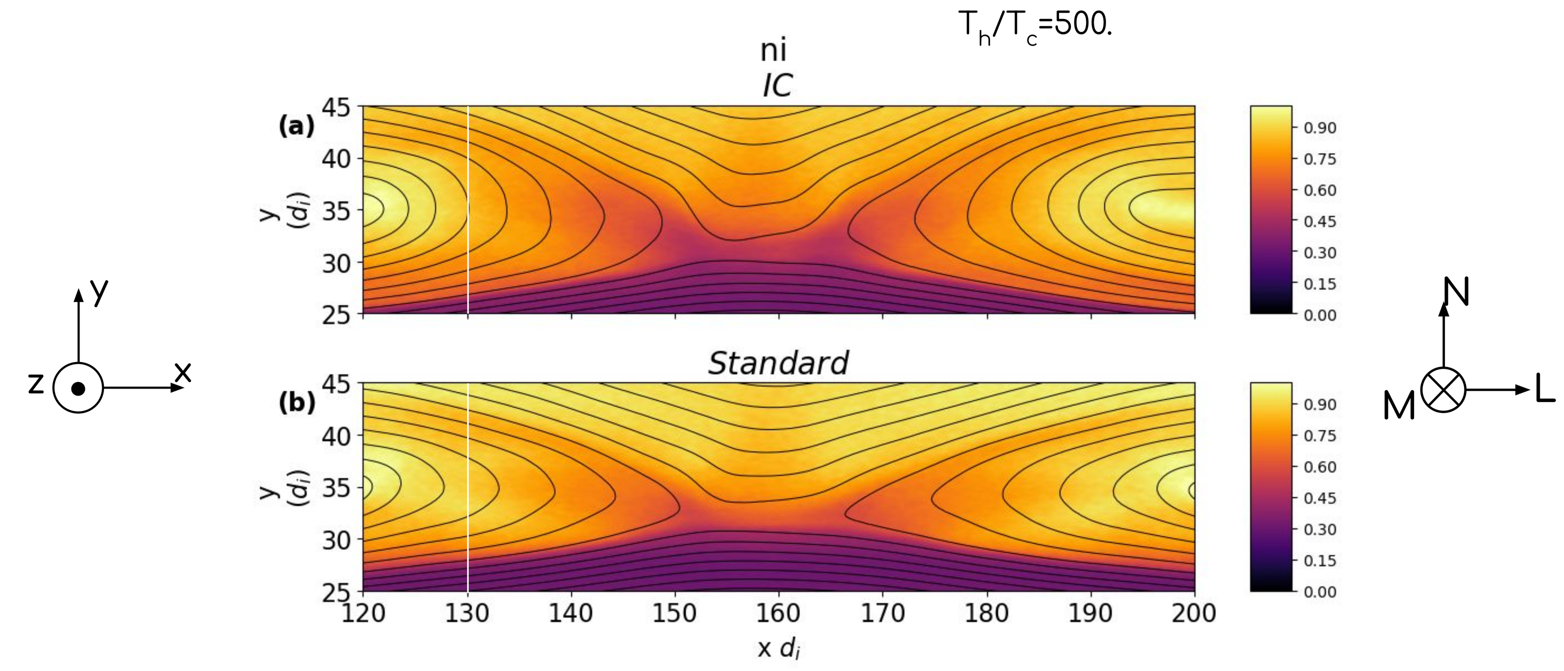

Figure 1. Density profiles for the Standard and cold-ion (IC) runs.

Results — Parallel Current Enhancement

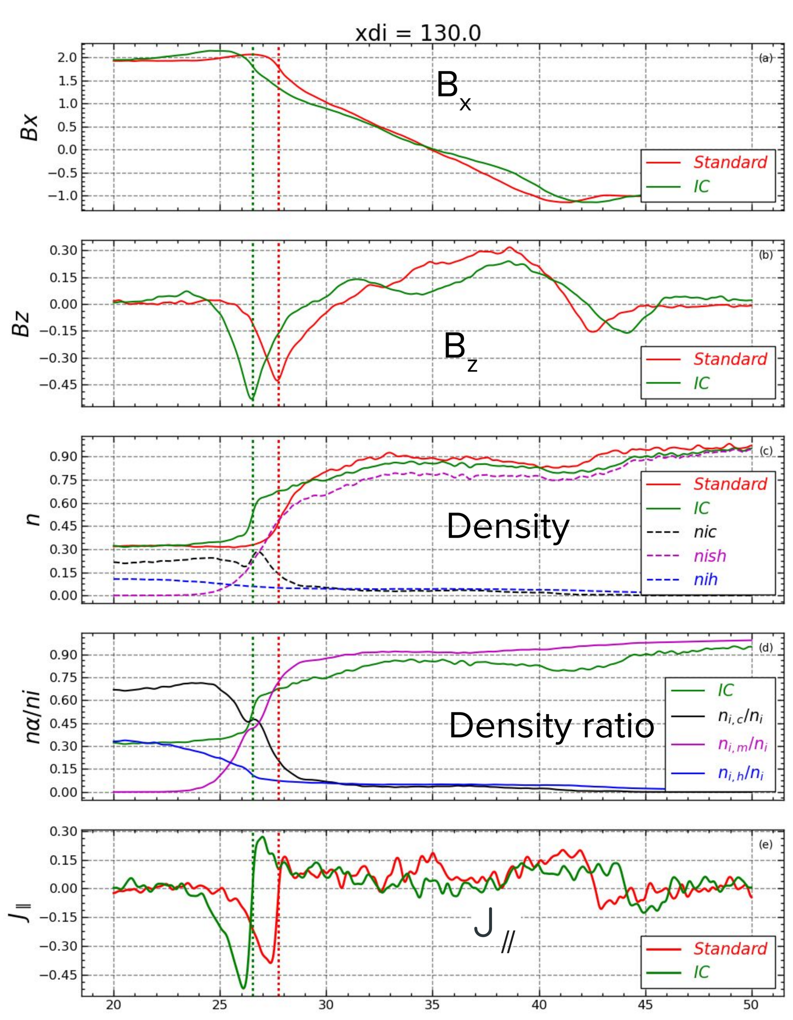

Figure 2. Profiles across the separatrix at x=130 d_i

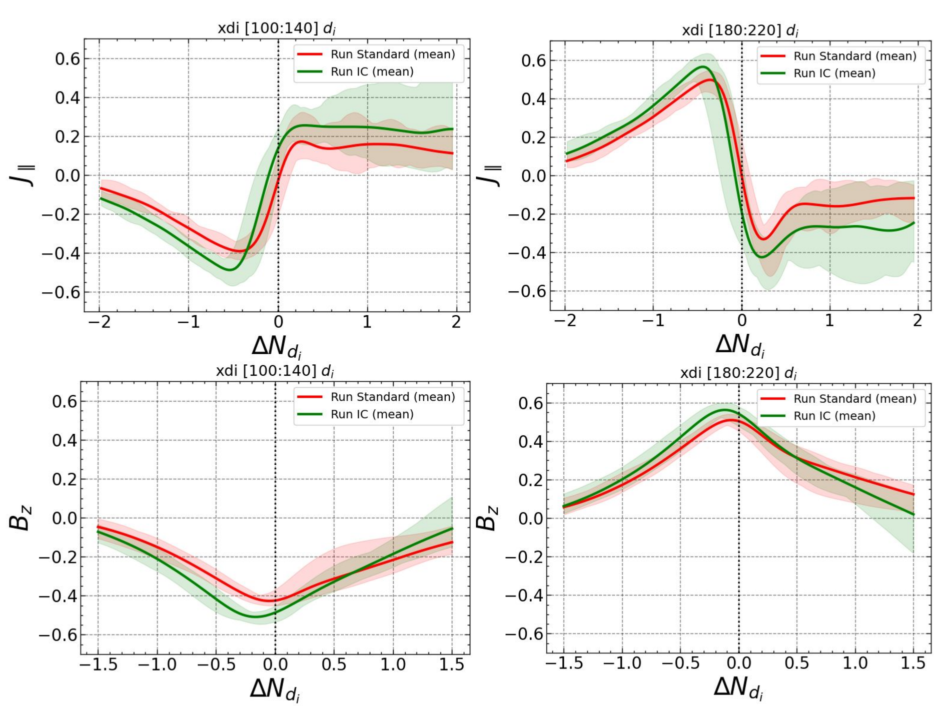

Figure 3. Separatrix-region variations of $J_{//}$, and Hall B_z along separatrix x- range

- Figure 2. A cut across the separatrix was taken at x=130 , far from the diffusion region, during quasi-steady reconnection (t=120).
- In the cold-ion run (IC) $J_{//}$ is enhanced relative to the standard run
- The Hall magnetic field is enhanced at the separatrix (20%).
- The separatrix location is shifted toward the magnetospheric side (green dashed line).
- Figure 3, tracking the separatrix over x = 100-140 and x = 180-220. The results show an enhancement of $J_{//}$, accompanied by an increase in the corresponding Hall magnetic field

Results — Electron Ohm's Law

From electrons Ohm's law:

$$\mathbf{E}' = \mathbf{E} + \mathbf{v_e} \times \mathbf{B} = -\nabla \cdot \mathbf{P}_e/ne$$

$$E' \simeq E'_{\parallel} \approx -(\nabla \cdot \mathbf{P}_e/ne)_{\parallel}$$

$$J_{//} . E'_{//} \simeq J_{//} . (-\nabla . P_e/ne)_{//}$$

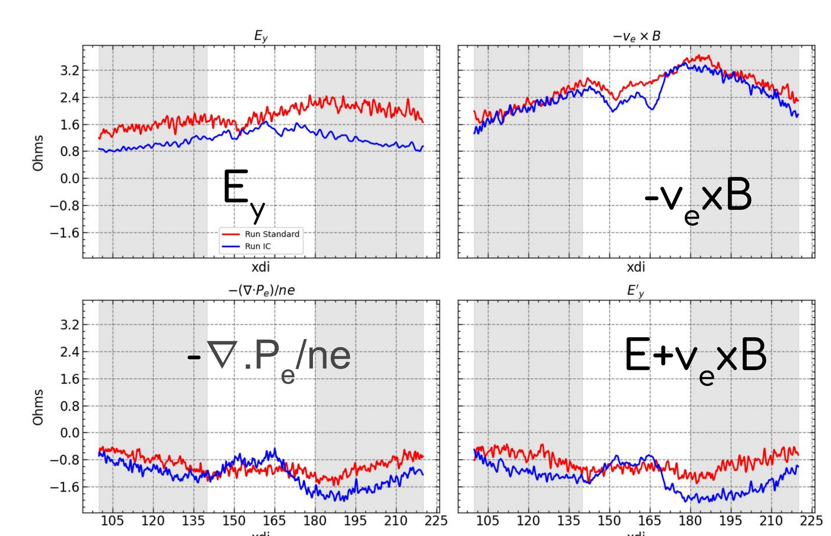

Figure 5. Electron Ohm's law terms across the separatrix for Standard and IC runs.

When cold ions are present:

- Peak E_y is reduced.
- **E+v_exB is enhanced along the separatrix.**
- The electron pressure-gradient contribution increases locally.
- **Non-ideal electron dynamics broaden away from the diffusion region.**
- This suggests a **redistribution** of electron momentum balance away from the diffusion region.
- Cold-ion effects therefore extend to separatrix-scale electron dynamics.

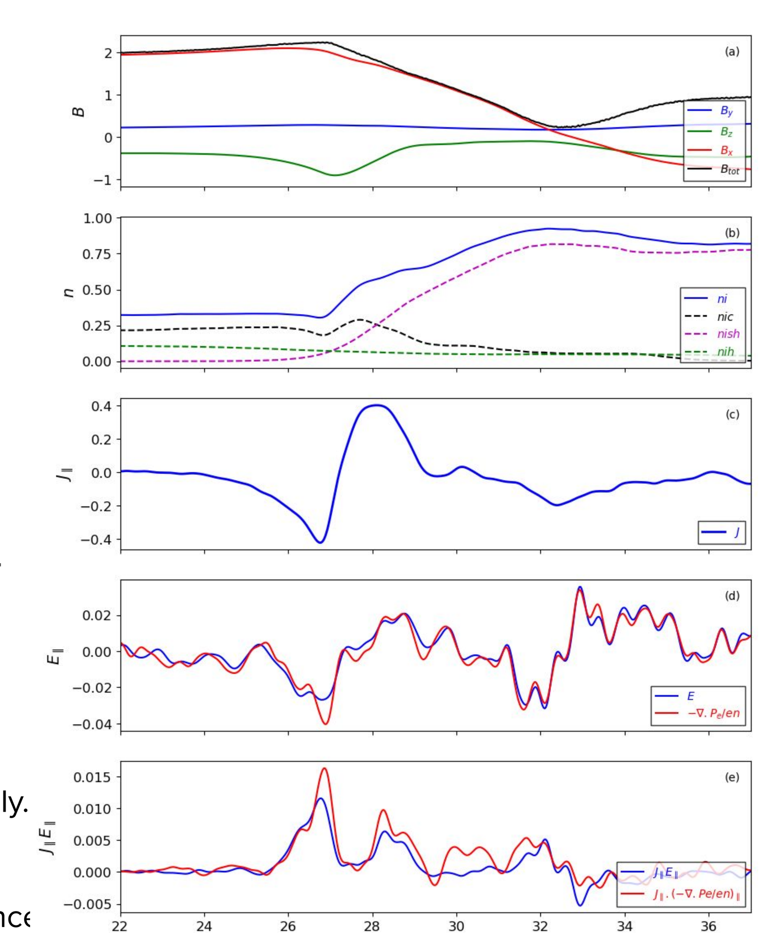

Figure 6. Parallel electron dynamics and pressure-gradient contributions near the separatrix.

$E_{//}\uparrow \longrightarrow J_{//}\uparrow$ (?)

Discussion — Separatrix Displacement

- Yellow dashed lines: Standard-run separatrices.
- Black dashed lines: Cold-ion (IC) separatrices.
- In the IC run, the separatrix is systematically displaced toward the magnetospheric side.
- Shift is systematic, not limited to a local perturbation.
- Enhanced $J_{//}$ and stronger Hall B_Z occur along the displaced separatrix.
- This suggests that cold ions modify ion-scale exhaust geometry in addition to local Hall physics.

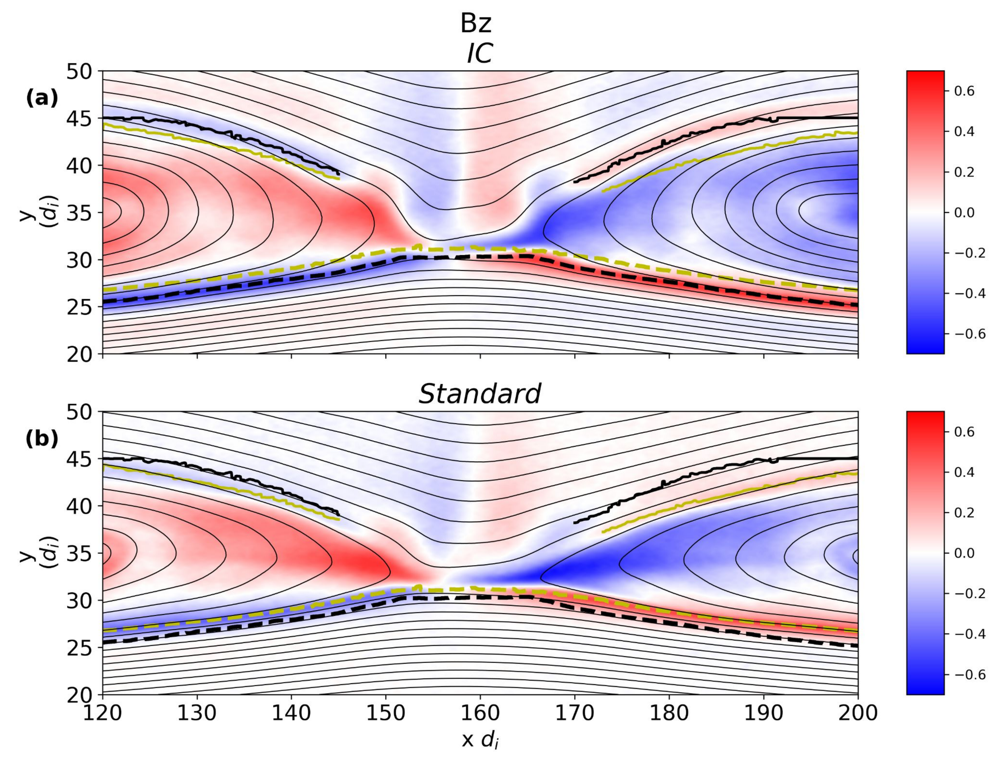

Figure 7 Comparison of separatrix locations in the standard and cold-ion runs. Cold ions shift the separatrix toward the magnetospheric side.

Conclusion

- Previous work showed that cold ions reduce the peak normal electric field E_y and perpendicular current (Toledo et al. 2018).
- Our results show that $J_{//}$ is enhanced in the Run IC suggesting a redistribution of Hall current closure along the separatrix.
- Our simulations further show theat cold ions reshape magnetopause reconnection topology

Cold ions reduce peak $E_N/J_{\perp}$, broaden the Hall region, enhance $J_{//}$, and shift the separatrix toward the magnetosphere.

References

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