# Achievement of the switch-off condition through compound Slow Shock/ Rotational Discontinuity structures in PIC simulations of collisionless magnetic reconnection with guide field

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## Introduction

In Petschek's model for fast magnetic reconnection, switch-off (SO) condition is achieved through back-to-back slow shocks (1)

Slow shock formation is observed in MagnetoHydroDynamics (2) and hybrid simulations (3); switch-off slow shocks have never been observed in Particle In Cell - PIC simulations, possibly also due to the computational costs of large domain PIC simulations

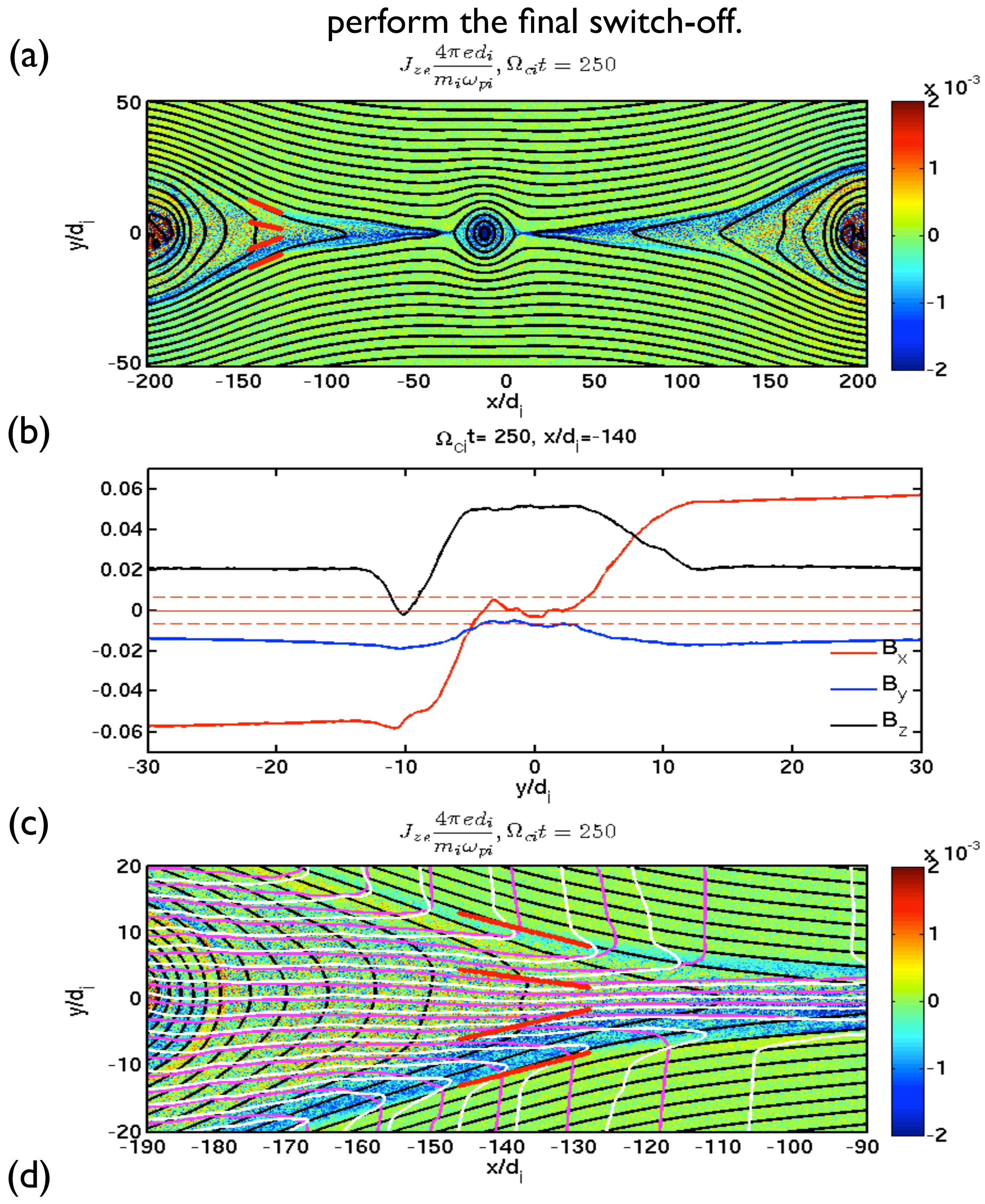
Recent 2D3V PIC simulations of anti-parallel reconnection show the formation of compound SS/RD structures; SO is not achieved due to the development of the firehose instability (4)

We investigate here SO condition in component magnetic reconnection; a guide field of Bg= 0.3 B0 is added to a simulation with otherwise the same parameters of (4)

The simulation we present is run in a large domain ($L_x/d_i$= 819.2, $L_y/d_i$= 409.6, with $d_i$ the ion skin depth) for a long physical time ($\Omega_{ci}t$> 250, with $\Omega_{ci}$ the ion cyclotron frequency)

## Switch-Off regions

As expected from (5), the guide field suppresses the development of the firehose instability. Switch-off is achieved in a significant fraction of the leftwards and rightwards exhausts through a compound Slow Shock/ Rotational Discontinuity structure. The external Slow Shocks located at the separatrices reduce the tangential component of the magnetic field; the internal Rotational Discontinuities perform the final switch-off.



(d)

| time $[\Omega_{ci}]$ | $\ell_{LW}$ $[d_i]$ | % LW exhaust | $\ell_{RW}$ $[d_i]$ | % RW exhaust |
|---|---|---|---|---|
| 180 | . | . | 12.5 | 11 % |
| 200 | . | . | 16.3 | 12.7 % |
| 220 | 8 | 6.2 % | 26.3 | 17.6 % |
| 240 | 23.7 | 16.4 % | 31.3 | 18.4 % |

Fig 1: (a) Out-of-plane electron current, showing the elongated Electron Diffusion Region and the formation of a long-lasting, large scale central plasmoid; (b) a vertical cut at $x/d_i$= -140 highlights a plateau of the magnetic field horizontal component at Bx~0, the switch-off region. (c) A zoom of the compound SS/RD area, with electron (white) and ion (purple) flow lines. Magnetic field lines are marked in black (d) In the table, the length of the SS/RD structures in the leftwards (LW) and rightwards (RW) exhausts and the percentage of each exhaust they covers at different times

## Characterization of the discontinuities

The external (internal) transitions are characterized as Slow Shock-SSs (Rotational Discontinuities- RDs) by checking the Rankine-Hugoniot jump conditions across the discontinuities, at different x coordinates

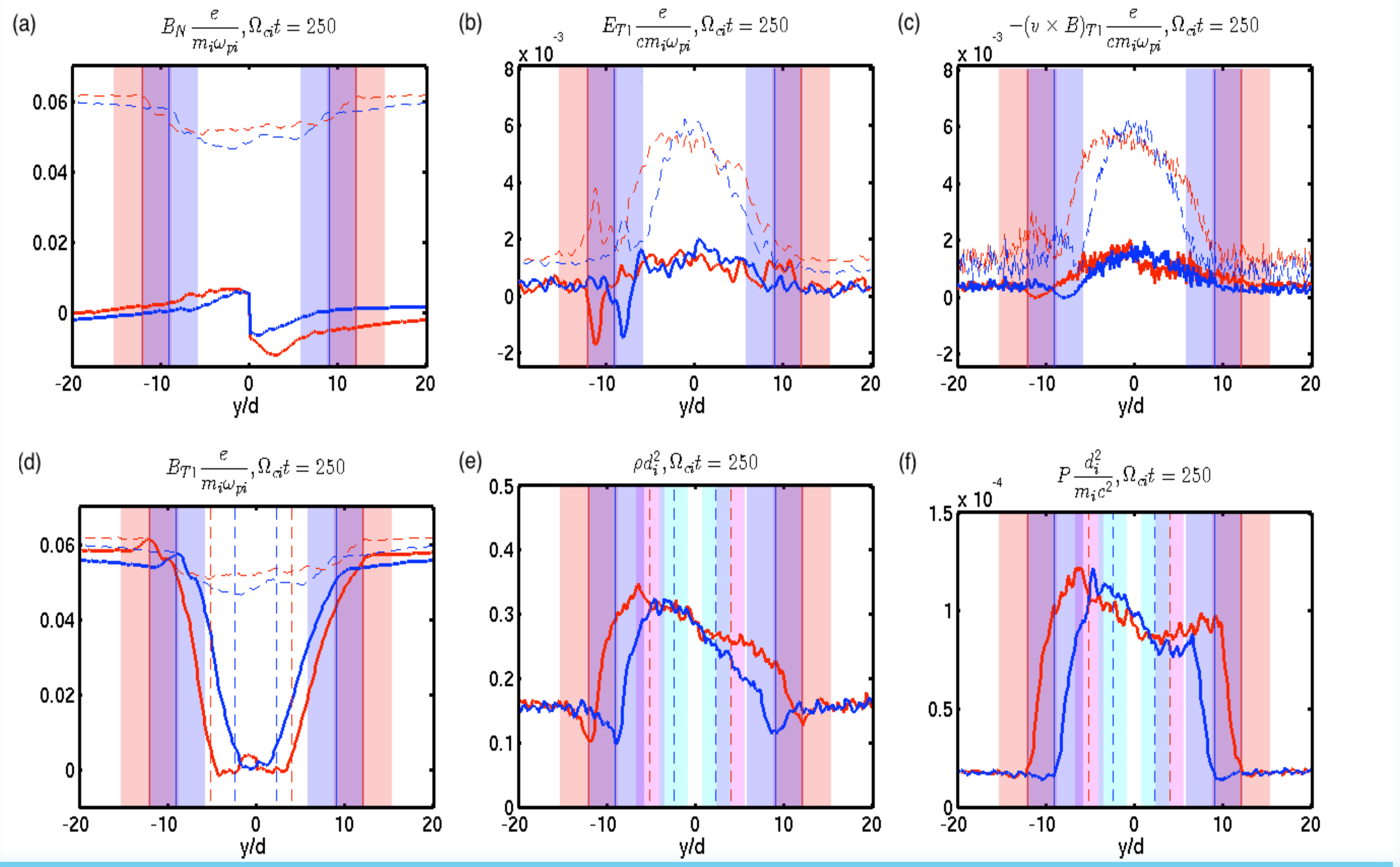


Fig 2: (a) $B_N$, (b) $E_{T1}$, (c)-$(v \times B)_{T1}$, (d) $B_{T1}$, (e) mass density $\rho$ and (f) total pressure P, in adimensional units, as a function of y/di and at the coordinates x/di = −143.1 (red line) and x/di = −132.2 (blue). The solid (dashed) vertical lines mark the position of the SSs (RDs) at the different x coordinates

As expected for SSs, $[B_N]$=0 (a), $[E_T]$=0 (the peaks in panel (b) are electron holes, compare with panel (c)), the tangential component of the magnetic field decreases (d) and the density (e) and pressure (f) increase across the discontinuities

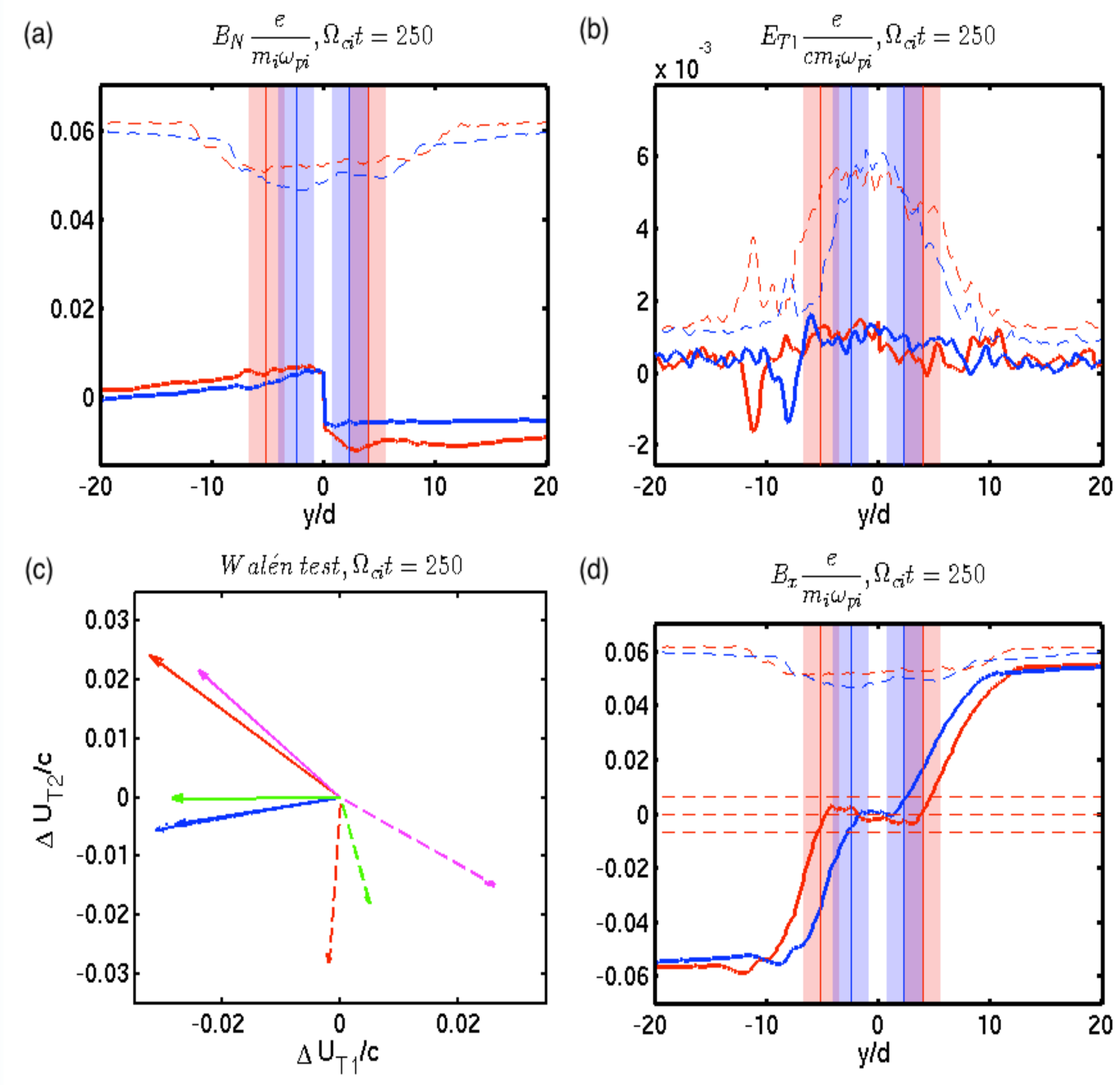


Fig 3: (a) $B_N$, (b) $E_{T1}$ (c) generalized Walen test for the four discontinuities in the tangential plane and (f) $B_x$, in adimensional units, as a function of y/di and at the coordinates x/di = −143.1 (red line) and x/di = −132.2 (blue). The solid vertical lines mark the positions of the RDs

As expected for RDs, $[B_N]$=0 (a), $[E_{T1}]$=0 (b) and the generalized Walen test is passed (panel c). The density and pressure are constant across the RDs, shown as dashed lines in Fig 2, panel (e) and (f). Panel (d) confirms the switch-off of the tangential component of the magnetic field

## Conclusions

- We have identified localized areas of switch-off in large-domain, long simulations of magnetic reconnection with guide field, where the guide field prevents the development of the firehose instability;
- Switch-off is achieved through a compound Slow Shock/ Rotational Discontinuity structure, not through slow shocks as expected from the Petschek's model
- The external Slow Shocks, located at the separatrices, and the internal Rotational Discontinuities are characterized as such by checking their Rankine-Hugoniot jump conditions and, for the RDs, the Walen condition

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