Particle-in-Cell simulation of Magnetotail Dipolarization Fronts and Associated Ion Reflection: Inflow density matters!

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Motivation: Upstream *inflow* density matters

Magnetotail lobe density is highly variable: $[0.007-0.092] \text{ cm}^{-3}$ with the most probable value $0.047 \text{ cm}^{-3}$ [Svenes et al., 2008].

Such lobe density ($n_b$) variation modifies reconnection diffusion region physical processes and reconnection rate drastically [Wu et al., accepted, Phys. Plasmas].

1. Violent and fast reconnection at small $n_b$
2. Faster outflow at $n_b$: $v_{\text{out}} \sim 0.4v_{A,\text{up}}$
   
   Ion meandering, larger diffusion region size, aspect ratio, and etc.

Here we address observable reconnection signatures in the downstream that are to be affected by the dynamic changes of reconnection.
Introduction: Dipolarization Front (DF)

Figure from Runov et al., 2009.

Also, observations of Ion acceleration [Zhou et al., 2010, 2011]
Introduction: Particle-in-Cell (PIC) simulations

Example: $n_b = 0.01$
Result: overview

“Fishbone” instability (courtesy of William H. Matthaeus for coining the term)

Wu et al., 2011, accepted, Phys. Plasmas
Result: reconnection rate vs. times at various densities

$E_R$ vs $t$ for different densities $n_b = 0.01, 0.015, 0.03, 0.1, 0.2, 1.0$

Wu et al., 2011, accepted, Phys. Plasmas
Result: Outflow

\[ v_{io} \sim 0.4v_{A,up} \]

Wu et al., 2011, accepted, Phys. Plasmas
Dipolarization Front (DF) and Front

\( n_B = 0.01 \) @ \( t=69 \)
\( n_B = 1.0 \) @ \( t=230 \)

Wu et. al. (2011), to be submitted to GRL
Dipolarization Front (DF) Propagation vs. Inflow Quantification

Wu et. al. (2011), to be submitted to GRL
Dipolarization Front (DF) Flow and Temperature (two extreme density cases)

\[ n_b = 0.01 \@ t=69 \]

\[ n_b = 1.0 \@ t=230 \]

\[ T_{xx} = \langle (v_x - u_x)^2 \rangle, \]

here \( v_x \approx u_x \) for most ions.

Wu et. al. (2011), to be submitted to GRL
Ion Reflection

Streaming acceleration: Very different from perpendicular shock ion reflection!

Localized to DF

Bipolar B field as consequence of Ion Streaming

Wu et. al. (2011), to be submitted to GRL
Summary: Effect of Inflow Density on Magnetic Reconnection

Downstream Dipolarization Front: as we lower inflow density

1. we quantify $B_{DF}$ and $v_{DF}$ scaling

2. We study Ion reflection in the self-consistent PIC simulation and find
   - Super-Alfvenic streaming,
   - Preferential heating in X,
   - Bipolar magnetic field,
   - As localized and transient as the DF.
Reconnection

We'll meet again
Don't know where
Don't know when

–Ross Parker
Particle-in-cell simulation

Code unit:

\[
\frac{\partial \gamma v_\alpha}{\partial t} = \frac{q_\alpha m_i}{m_\alpha} [\mathbf{E} + v_\alpha \times \mathbf{B}]
\]

\[
\frac{\partial x_\alpha}{\partial t} = v_\alpha
\]

\[
\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}
\]

\[
\frac{\partial \mathbf{E}}{\partial t} = \frac{c^2}{v_{A0}^2} (\nabla \times \mathbf{B} - \mathbf{J})
\]

\[
\nabla \cdot \mathbf{E} = \frac{c^2}{v_{A0}^2} (n_i - n_e)
\]

Normalization:

\( B_\infty, n_0, m_i, d_i, v_{A0}, \)

\( E: \frac{v_{A0} B_\infty}{c}, \quad T: m_i v_{A0}^2 \)

Prescriptions: \( m_e = 0.04, \quad c = 15 \)
Harris-like current sheet

(center)

n(z)

n₀

B∞

Bₓ(z)

n₀

width w₀

z

nᵦ