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Direct evidence of secondary reconnection inside filamentary currents of magnetic flux ropes in magnetic reconnection

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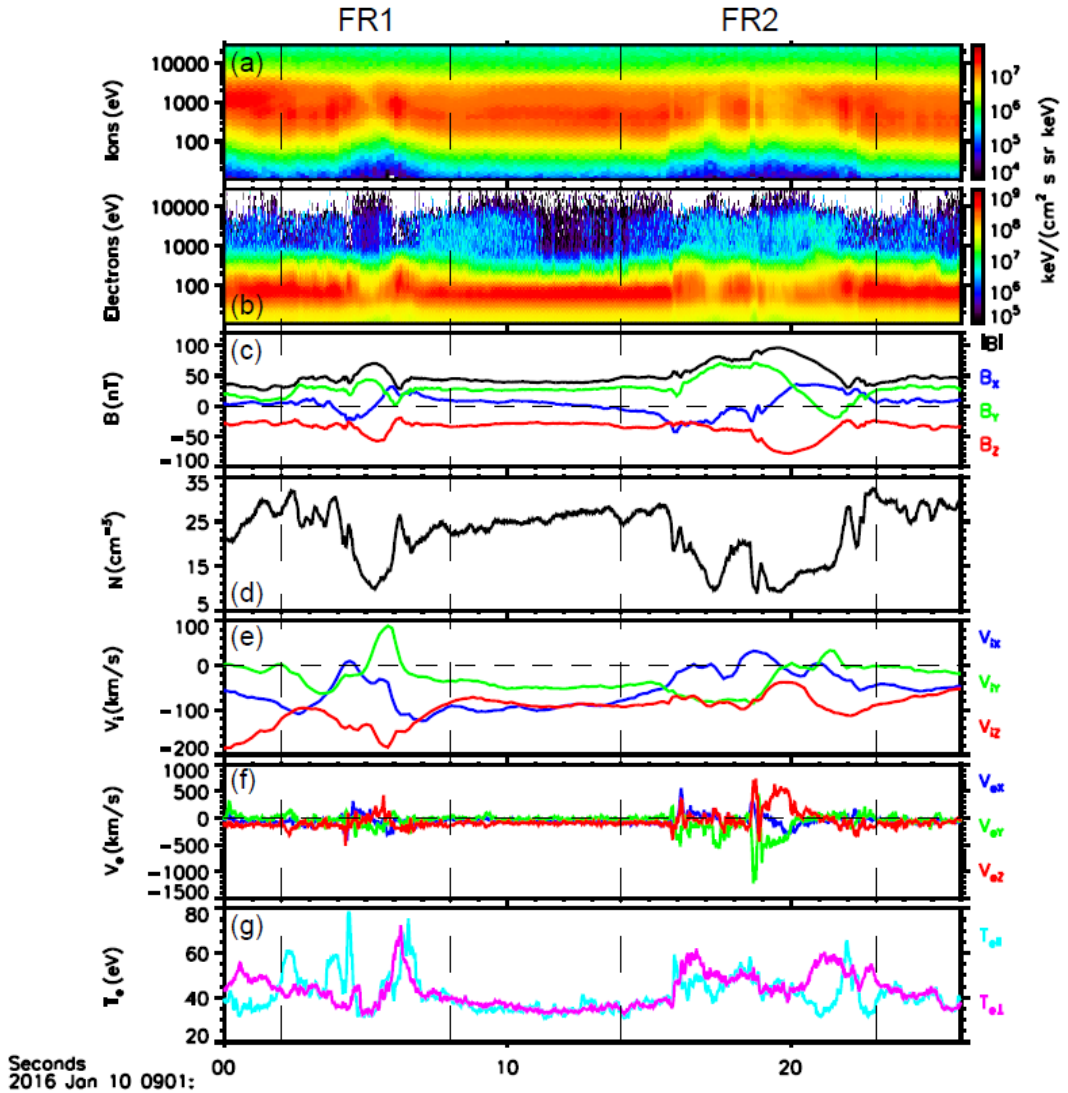
Introduction

- Magnetic reconnection is a fundamental plasma process by which magnetic energy is released in the current sheet to energize charged particles and to create bi-directional Alfvénic plasma jets.
- Numerical simulations predicted that evolution of reconnecting current sheet was dominated by formation and interaction of magnetic flux ropes (e.g., *Daughton et al., 2011*).
- Recently, intense electric field structure and energy dissipation were detected inside flux ropes (*Stawarz et al., 2018; Wang et al., 2016; Fu et al., 2016; Huang et al., 2019*).

Observations



An overview of the MMS observations dawn-side of Earth's magnetopause.

Two flux ropes (bounded by the vertical dashed lines) were observed in the southward reconnection outflow (0.8 V_A).

Scales: FR1, ~119 km/s, 7.8 d_i

FR2, ~72 km/s, 7.1 d_i

Electron flow spikes in flux ropes.

Enlarged view of two flux ropes

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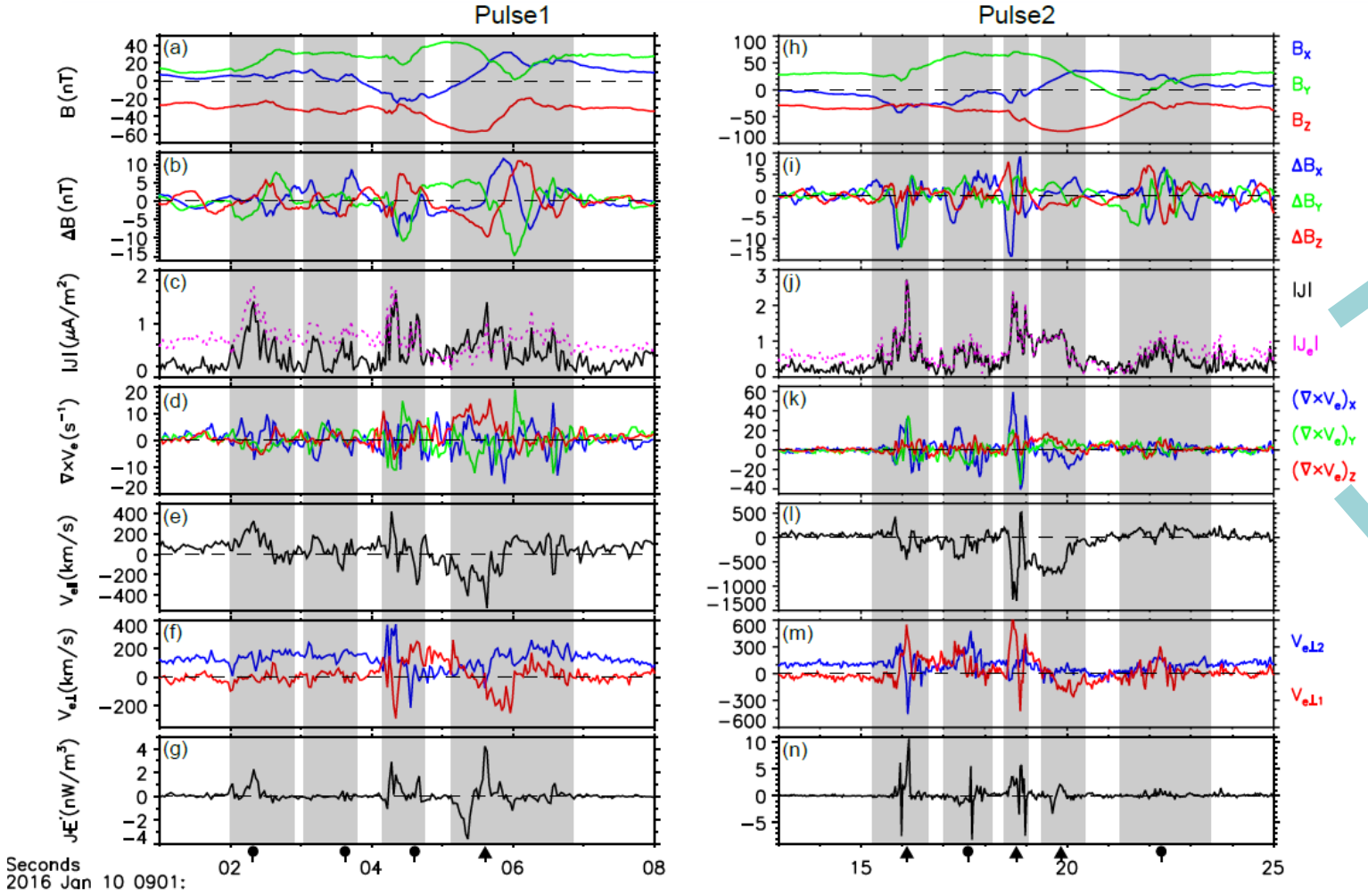

Shadows: varied magnetic field pulses.

Clear filamentary currents inside flux ropes.

Significant electron flow vorticity in varied magnetic field pulse.

The strong energy conversion ($J \cdot E'$) occurred in the extremely localized area within the magnetic field pulses.

Relation between energy conversion and current density

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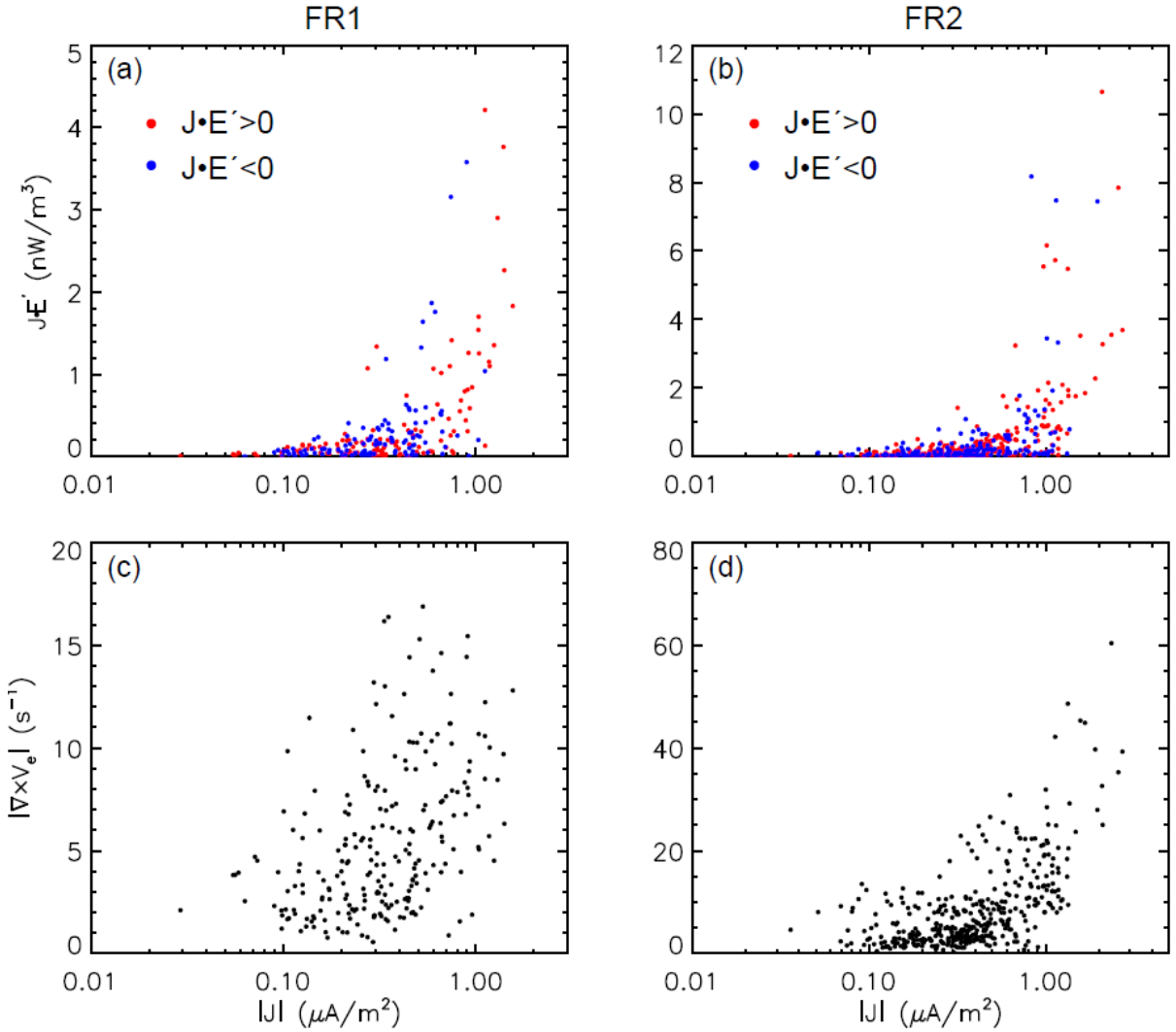

The most intense energy conversion only appeared at strong current density.

The positive data points (>0.5 nW/m^3) were more than the negative points: there is net magnetic energy release.

On average, the magnetic free energy was dissipated inside two flux ropes.

Direct evidence of secondary reconnection in filamentary currents

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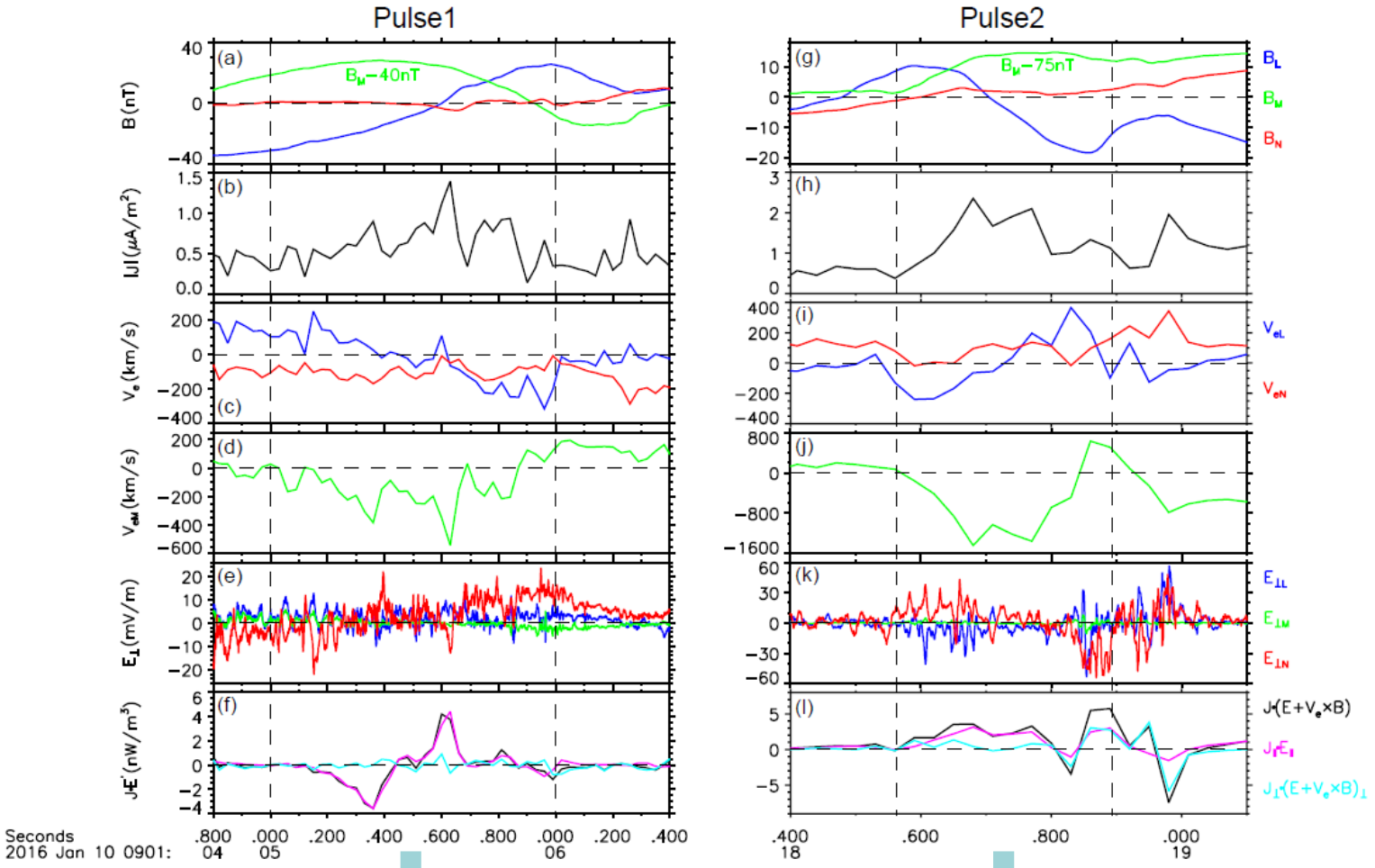
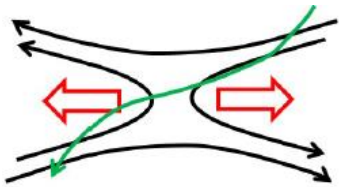


Reconnection signatures:

1. Bi-directional electron outflow jets (panel c and i).
2. Hall electric field (panel e and k).
3. Significant energy dissipation (panel f and l).



Cross the reconnection diffusion region from one outflow to the other

1.4 d_i

0.37 d_i

The reconnection was common in these varied magnetic field pulses.

Conclusion

1. Inside two big flux ropes embedded in the reconnection ion outflows, we find a few small-scale flux rope-like structures or the varied magnetic pulses.
2. The secondary reconnection was first detected inside these pulses.
3. Magnetic energy was released inside magnetic flux ropes via secondary reconnection and they may make a significant role on energy conversion during reconnection.