Electron Acceleration in the Reconnection Diffusion Region: Cluster Observations

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Abstract

We present one case study of magnetic islands and energetic electrons in the reconnection diffusion region observed by the Cluster spacecraft. The cores of the islands are characterized by strong core magnetic fields and density depletion. Intense currents, with the dominant component parallel to the ambient magnetic field, are detected inside the magnetic islands. A thin current sheet is observed in the close vicinity of one magnetic island. Energetic electron fluxes increase at the location of the thin current sheet, and further increase inside the magnetic island, with the highest fluxes located at the core region of the island. We suggest that these energetic electrons are firstly accelerated in the thin current sheet, and then trapped and further accelerated in the magnetic island by betatron and Fermi acceleration.

Introduction

Magnetic reconnection is a fundamental mechanism in space and laboratory plasma that enables reconfiguration of magnetic field topology and converts magnetic energy into plasma kinetic and thermal energies.

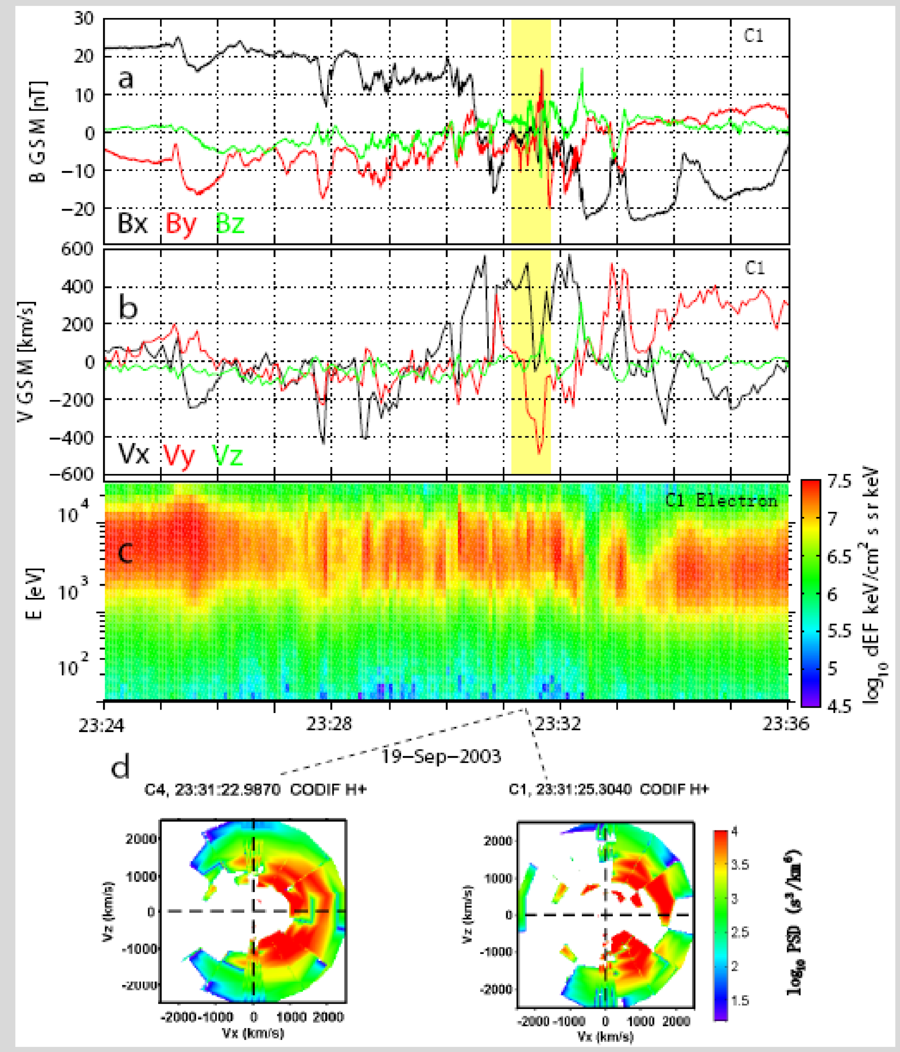
It is believed that magnetic islands or flux ropes (both referred to as magnetic islands below) play an essential role in the physics of magnetic reconnection and can be formed by multiple X-lines reconnection [e.g. *Slavin et al.*, 2003]. Recent kinetic simulations show that smaller scale secondary islands can be formed in the diffusion region due to the unstable tearing mode during reconnection with or without guide field. Such magnetic islands have been observed inside or near the ion diffusion region in the Earth's, but also have been detected far away from the reconnection site.

Magnetic islands are closely related to electron acceleration during reconnection. Recently, direct correlations between the islands and acceleration of electrons was observed in the magnetotail. *Drake et al.* [2006] put forward a scenario that electrons gain kinetic energy by reflecting from the ends of contracting islands due to the Fermi acceleration. The electrons can be also accelerated during multi-island coalescence [*Tanaka et al.*, 2011] or trapped in the islands and energized by the reconnection electric field [*Oka et al.*, 2010].

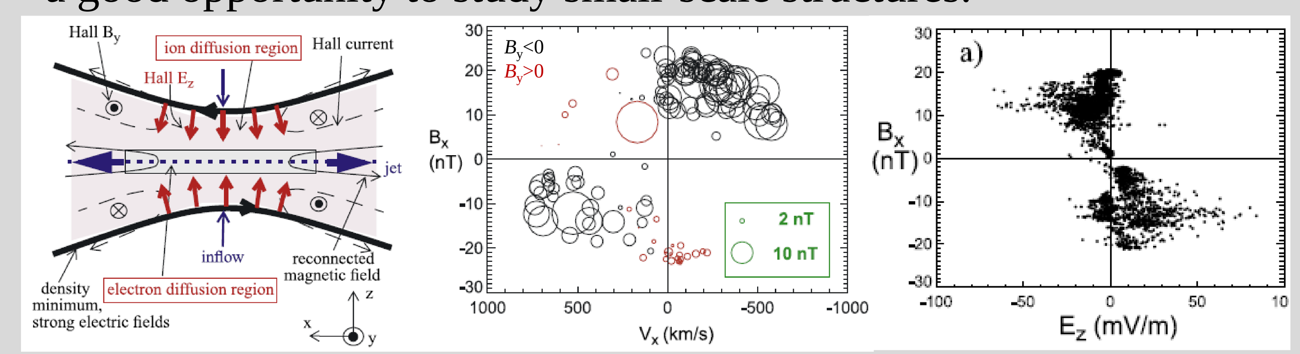
In this study, we use the Cluster multi-spacecraft observations to study energetic electrons and magnetic islands in the reconnection diffusion region.

Cluster Observations

➢ Identification of Reconnection Diffusion Region

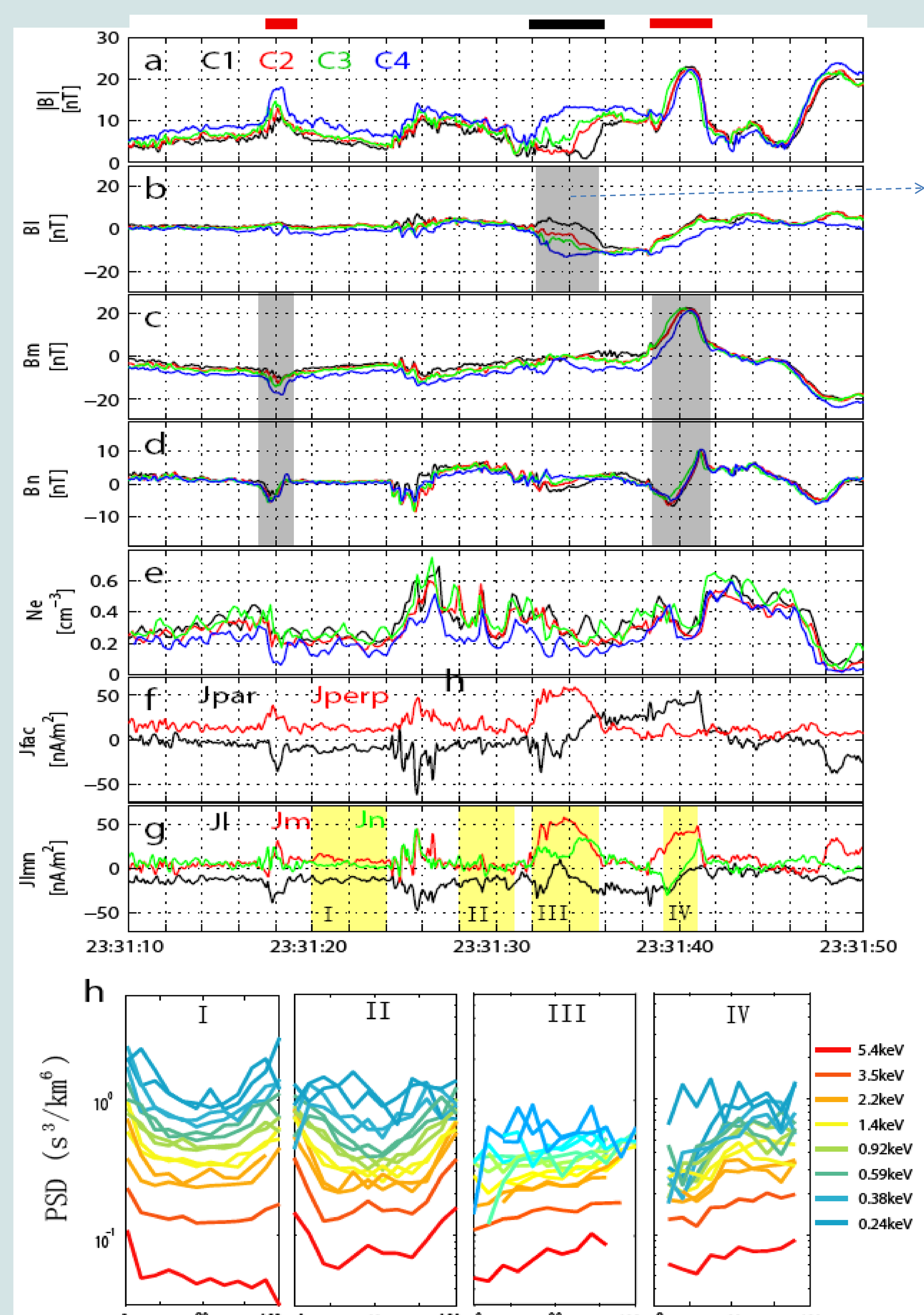


- Cluster was located at (-17.4, 3.7, 0.5) Re (the Earth's radius) in Geocentric Solar Magnetospheric (GSM) coordinates with an inter-spacecraft separation of ~200 km (much smaller than ion inertial length in the magnetotail). Such small separation provides a good opportunity to study small-scale structures.



- *Borg et al.*, [2006] identified the interval of 23:25:15 - 23:34:00 UT as a diffusion region crossing owing to a Hall quadrupolar structure of the out-of-plane magnetic fields and bipolar Hall electric fields pointing toward current sheet in the normal direction.
- Proton distributions consist of two beams with positive and negative V_z, and positive V_x, consistent with proton distributions within diffusion region seen in hybrid simulations [*Aunai et al.*, 2011]

➢ Observation of Magnetic Islands and Thin Current Sheet



B_t peak

Thin current sheet

Core field: B_m peak

Bipolar structures: -/+ bipolar signature in B_n

Density depletion inside the magnetic islands

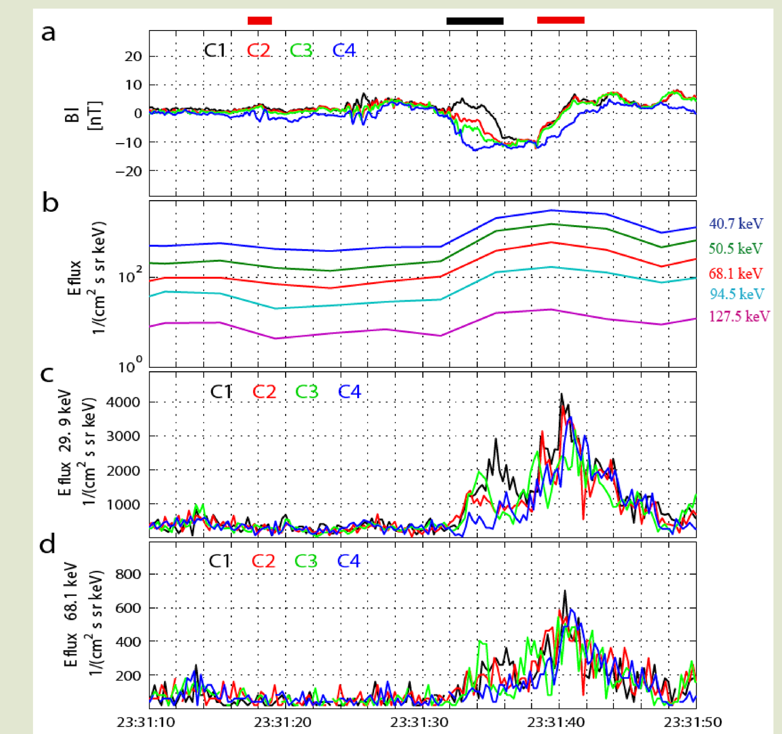
Large parallel current,
un-neglectable perpendicular current

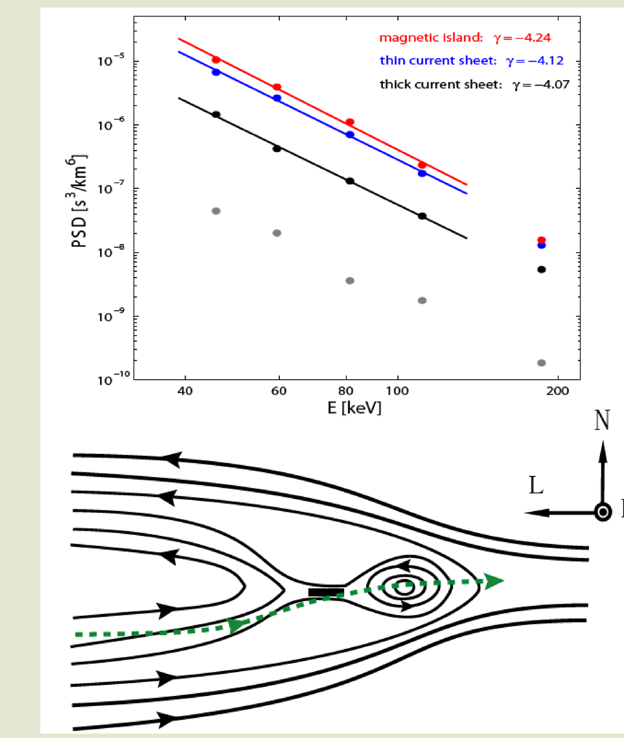
Large axial current

Field-aligned bidirectional distribution, i.e. intensification of the PSD at 0° and 180° in the thick current sheet.

Anti-parallel direction in the thin current sheet and magnetic island.

➢ Observation of Energetic Electrons





- The energetic electrons are only observed in the thin current sheet and the second magnetic island especially the highest enhancement in the density dip.
- The observed power law index of energetic electrons in the magnetic island is similar to that in the thin current sheet, which gives strong evidence for an adiabatic acceleration process, such as betatron and/or Fermi acceleration.
- These electrons maybe first accelerated in the thin current sheet, and then trapped in the magnetic island and further accelerated by betatron and Fermi acceleration.

Summary and Conclusion

- We presented Cluster observations of two magnetic islands and a thin current sheet embedded in the earthward plasma flow in the reconnection diffusion region.
- There are density depletions in the core region of the islands and intense currents therein which are dominantly parallel to $\mathbf{B}_0$ and have a large component along the island axis. There is also non-zero perpendicular current component present which indicates that the islands are not in force-free magnetic field configuration.
- Energetic electrons are only observed in the thin current sheet (energetic electrons fluxes in the center are larger than at the edge) and in the second magnetic island. The greatest enhancement is near the core of the island. These energetic electrons may have been first accelerated in the thin current sheet, and then trapped and further accelerated in the magnetic island by betatron and Fermi acceleration.

Acknowledgement

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