Statistical Analysis of Magnetic Cloud Erosion by Magnetic Reconnection


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Outline

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• Event Study: 19-20 November 2007
  - Direct method
  - Signatures of reconnection
• Statistical Study
• Conclusion
Magnetic cloud characteristics

Basic properties:
Magnetic cloud can be distinguished by:

- Relatively strong magnetic field
- Large and smooth B-field rotation
- Lower temperature than average

Other signature: counter-streaming beam of suprathermal electrons [Gosling et al., 1987]

Magnetic structure:
Toroidal structure, different models:

- Cylindrical model (locally described as cylinder) [Lepping et al., 1990]
- Non-cylindrical model (expansion during propagation), ...

[Burlaga et al. 1981]
Erosion by magnetic reconnection

Recent observations of reconnection exhausts in solar wind (Gosling et al., 2005; Phan et al., 2006; Lavraud et al., 2009), some associated with CMEs (Farrugia et al., 2001)

Magnetic reconnection proposed as process to erode MC flux (McComas et al., 1988; Dasso et al., 2006)

MHD simulation of erosion

(Schmidt and Cargill, 2003; Taubenschuss et al., 2010)
Event Study

19-20 November 2007

Multi-spacecraft Analysis: ST-A, B, ACE, WIND, THEMIS B
Overview of the event: 19-20 November 2007

ACE, ST-A, ST-B locations and orientation of the axis derived from MVA

Event seen at ACE

Event also studied by Farrugia et al. (2011) and Gosling et al. (2008) for different purposes

→ 3-nicely separated spacecraft observation of a clean magnetic cloud
Direct Method (Dasso et al., 2006)

- Calculation of accumulative azimuthal flux along spacecraft trajectory (in proper frame).

- Asymmetry in the flux balance with excess flux at the back of the MC may reveal erosion by magnetic reconnection at its front.

- Accumulative flux per unit length:

\[
\frac{F_y(x)}{L_{in}} = \int_{t_{in}}^{t(x)} B_{y,cloud}(t') * V_{x,cloud} \, dt'
\]
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Direct Method - Results

Cloud axis determination:
1) MVA (minimum variance analysis) AND bootstrap error estimates
2) Cloud-fitting method: MC is described by a force-free model

→ Presence of back region with excess flux at both ST-A and ACE
Local reconnection

Reconnection signatures

- Presence of bifurcated current sheets
  - At all spacecraft

- Valid Walén test
  - At ST-A and THEMIS
    (ACE and ST-B too coarse resolution)

Reconnection signatures found at front of MC at each spacecraft
Statistical study (with WIND data)

- Lepping List 1995-2008 → 109 cases examined
- Boundary determination: ‘case by case’
- Axis orientation with MVA and FRF
- Looking for erosion at the front AND at the rear!

Selection Criteria:

Boundaries well determined + Axis orientation from MVA

- Angle $-45^\circ < \lambda < 45^\circ$ → not crossing a leg
- Ratio intermediate / minimum eigenvalue $>2$
- Ratio maximum / intermediate eigenvalue $>2$
- $\Delta\theta$ and $\Delta\phi < 15^\circ$ (error estimates from bootstrap method)
- Impact parameter $< 0.6$

= 42 MCs (remaining/109)

Janvier et al. [2013]
Results from MVA

Signature of MC erosion with direct method for 42 MCs

Distribution:
53% MCs eroded at the front

$\Delta V$ Vs. Amount of azimuthal eroded flux

47% MCs eroded at the rear

$\Rightarrow$ No correlation found between $\Delta V$ (MC mean speed – Solar Wind Speed before the front boundary) and the amount of eroded flux at the front and at the rear of the MCs
**Signature of magnetic reconnection**

Presence of magnetic reconnection signatures at FRONT and REAR boundaries

Categorization of Exhausts
→ Walén Test and Data quality

- **At the front boundaries:**
  For the set of MCs where front boundaries are well localized
  16 signatures = 20%

- **At the rear boundaries:**
  For the set of MCs where rear boundaries are well localized
  16 signatures = 31%
Conclusion

Summary of signatures compatible with MC erosion

- Acc. Azimuthal Flux (Dasso et al. 2006, direct method)
- Reconnection signatures at MC boundaries
- Pitch Angle Distributions of suprathermal electrons in MC back show clear changes as compared to the core of the MC (not shown here)

Statistical Study

- 47% MCs eroded at the rear and 53% at the front
- 31% reconnexion signatures found at the rear and 20 % at the front
- No correlation found between local ΔV and amount of eroded flux

→ Impact on geo-effectiveness