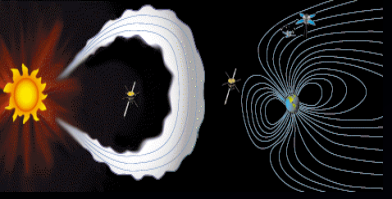

Statistical Analysis of Magnetic Cloud Erosion by Magnetic Reconnection

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Outline

- Introduction
- 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 :
[*Burlaga et al. 1981*]

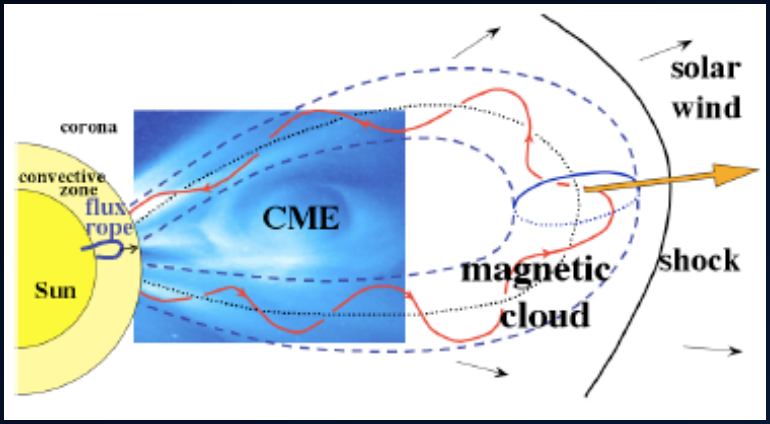
- Relatively strong magnetic field
- Large and smooth B-field rotation
- Lower temperature than average

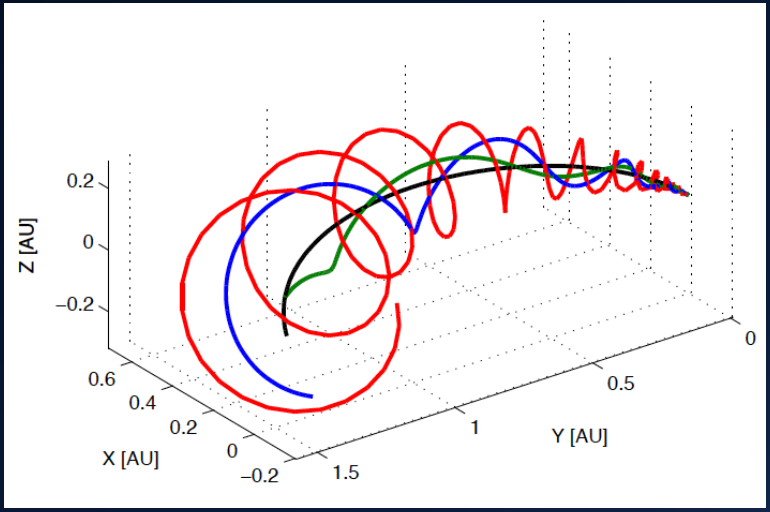
Other signature : counter-streaming beam of suprathermal electrons [*Gosling et al.*, 1987]

Magnetic structure:

Toroidal structure, different models :

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

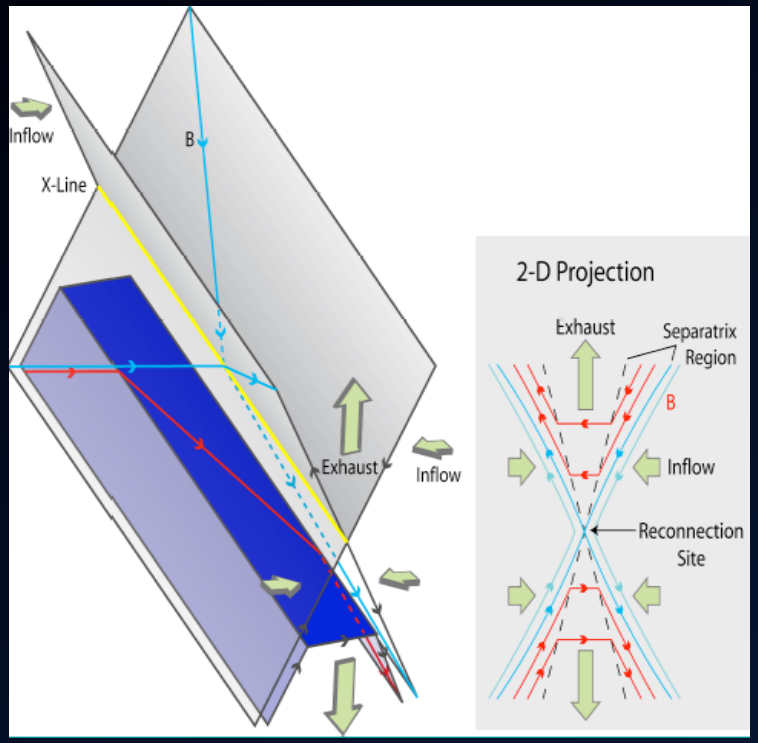




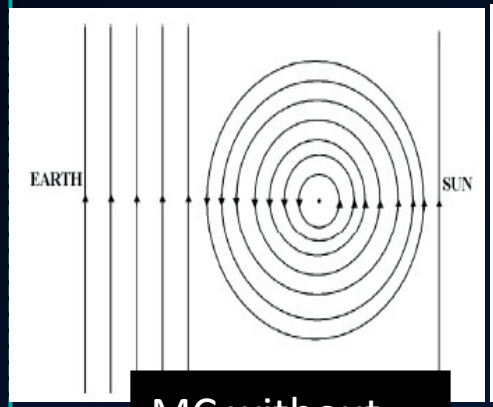
Owens et al. (2012)

Erosion by magnetic reconnection

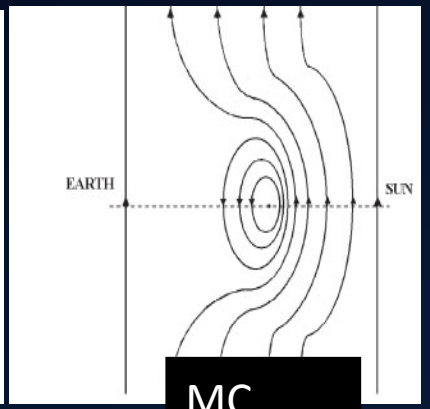
Recent observations of reconnection exhausts in solar wind (Gosling et al., 2005 ; Phan et al., 2006; Lavraud et al., 2009), some associated with CMEs (Farrugia et al., 2001)



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



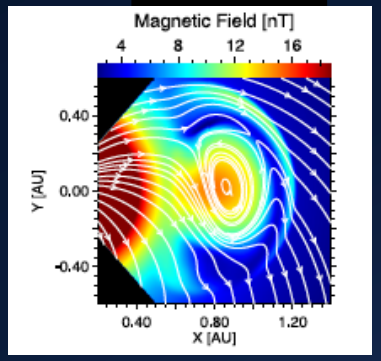
MC without erosion



MC eroded

MHD simulation of erosion

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

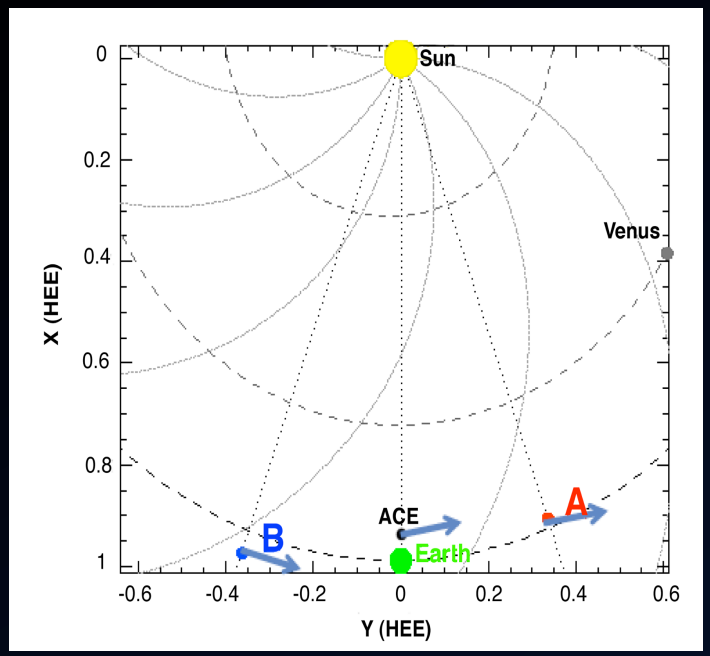


Event Study

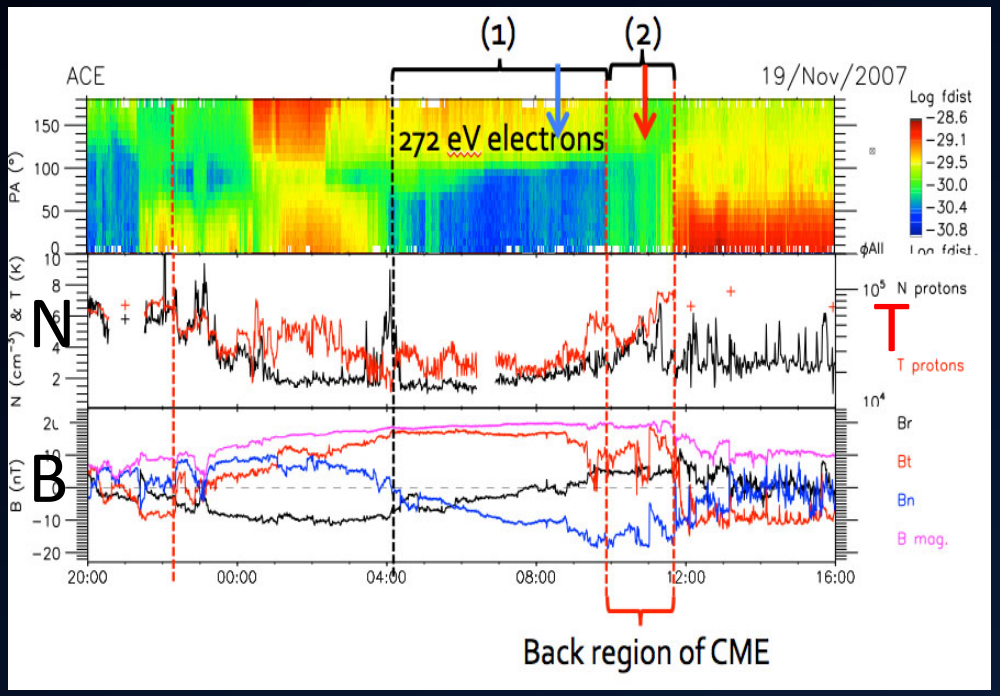
19-20 NOVEMBER 2007

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

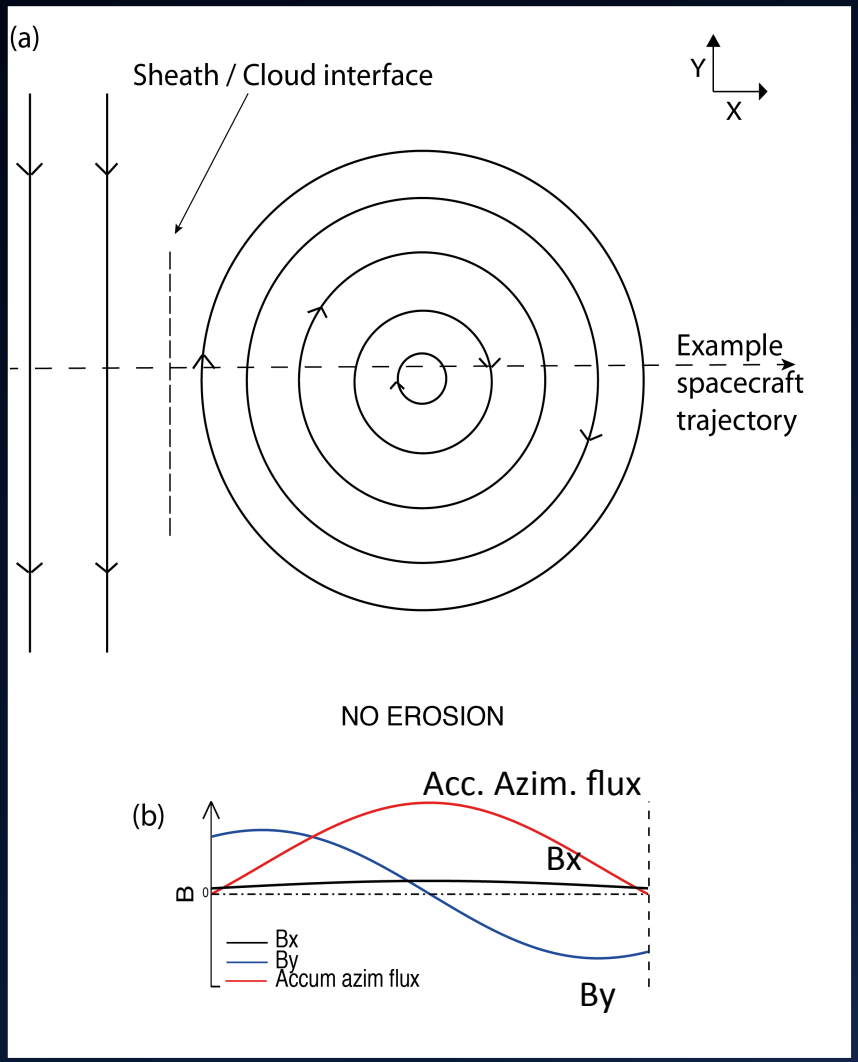
Event also studied by Farrugia et al. (2011) and Gosling et al. (2008) for different purposes

→ 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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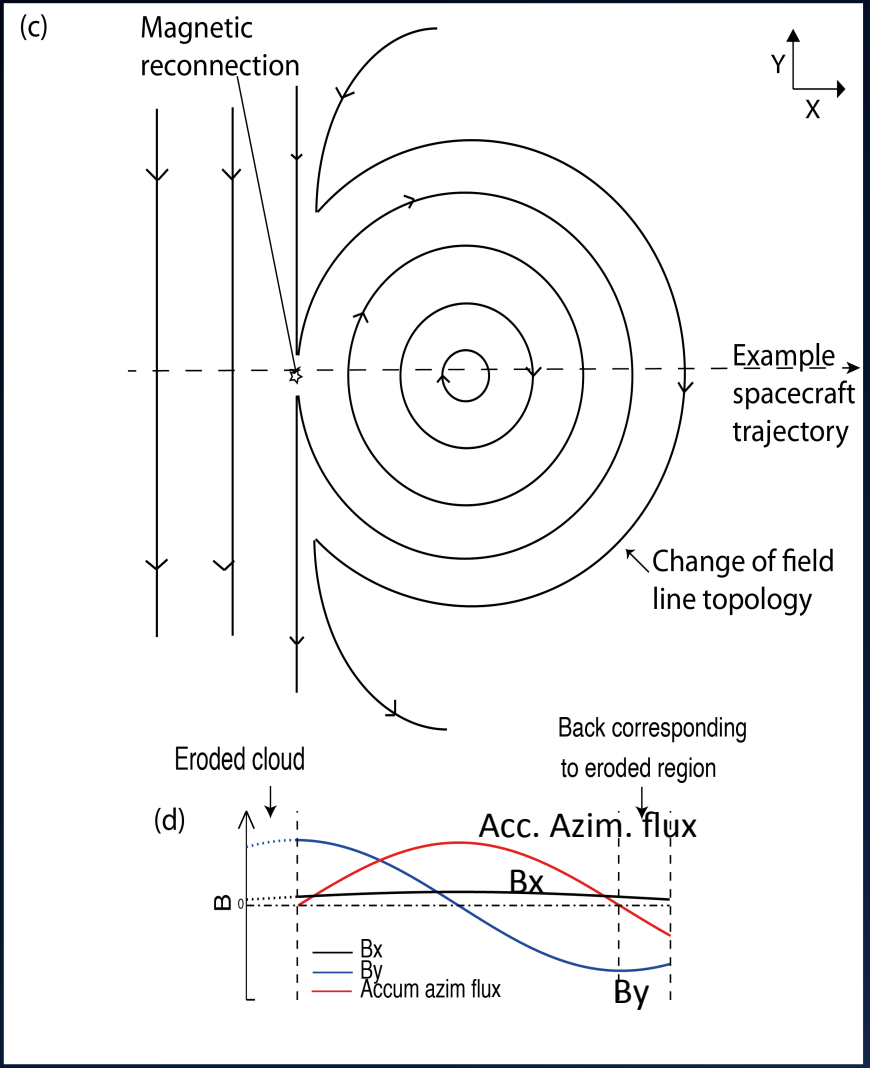
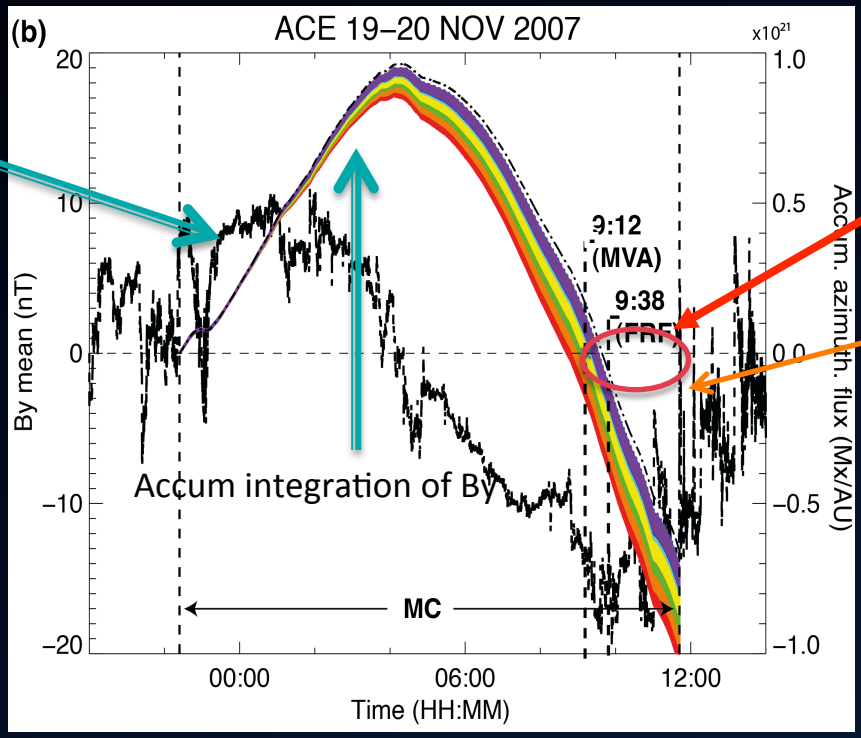


Direct Method - Results

By component
(MC coordinate system)



« Back » region of MC

End of cloud

Cloud axis determination :

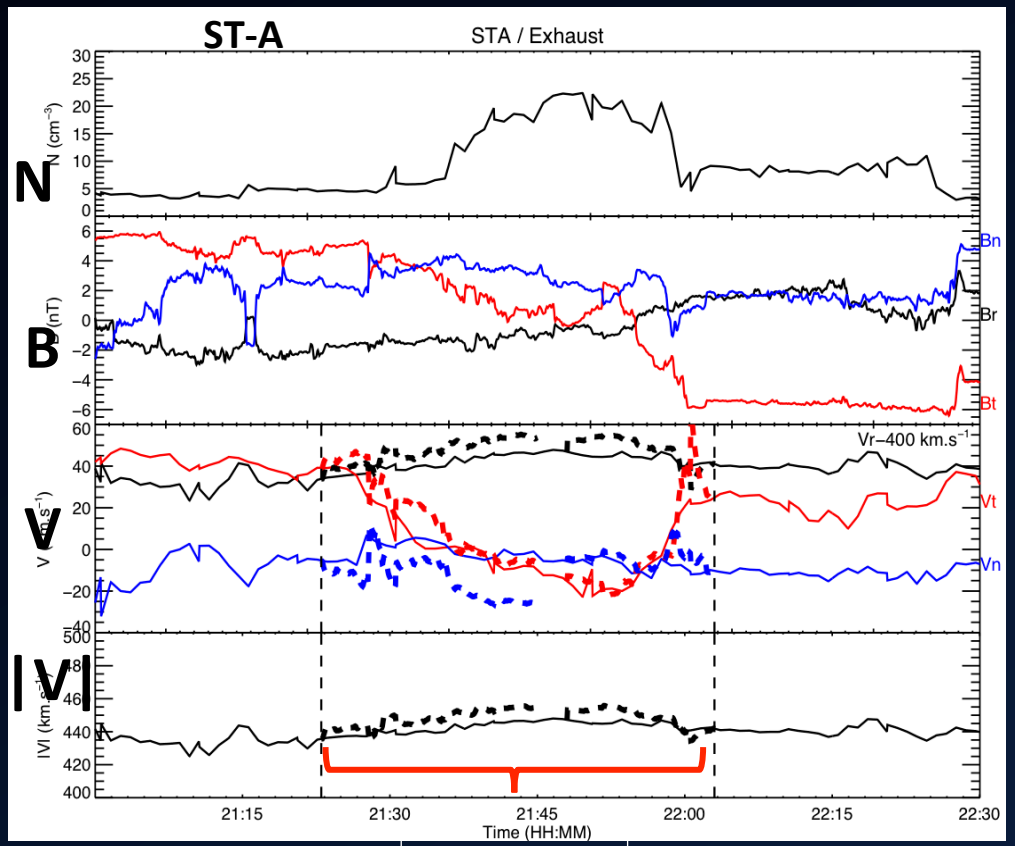
1) MVA (minimun variance analysis) AND bootstrap error estimates
2) Cloud-fitting method : MC is described by a force-free model

→ 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)



Exhaust

→ **Reconnection signatures found at front of MC at each spacecraft**

Statistical Study

MC EVENTS 1995-2008

Statistical study (with WIND data)

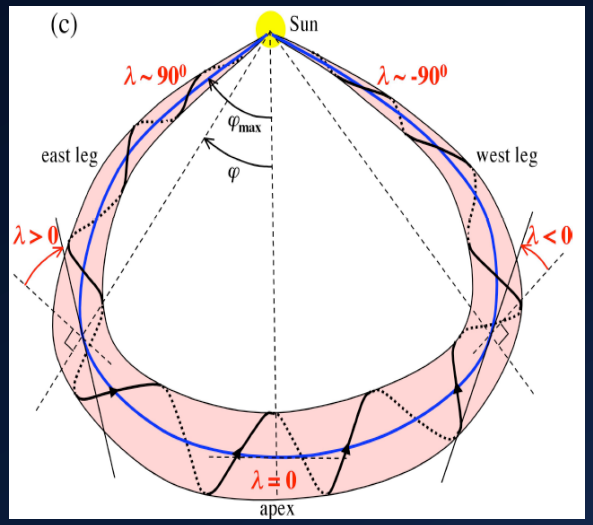
- Lepping List 1995-2008 → 109 cases examined
- Boundary determination : 'case by case'
- Axis orientation with MVA and FRF
- Looking for erosion at the front AND at the rear !

Selection Criteria:

Boundaries well determined + Axis orientation from MVA

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

= **42 MCs (remaining/109)**



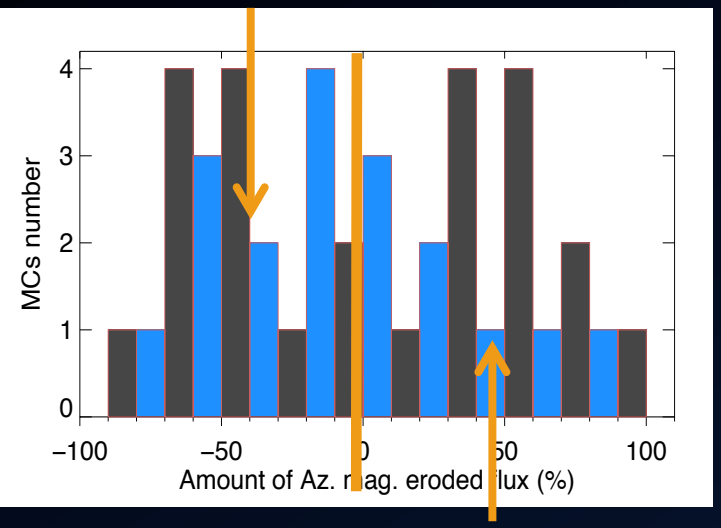
Janvier et al. [2013]

Results from MVA

Signature of MC erosion with direct method for 42 MCs

Distribution:

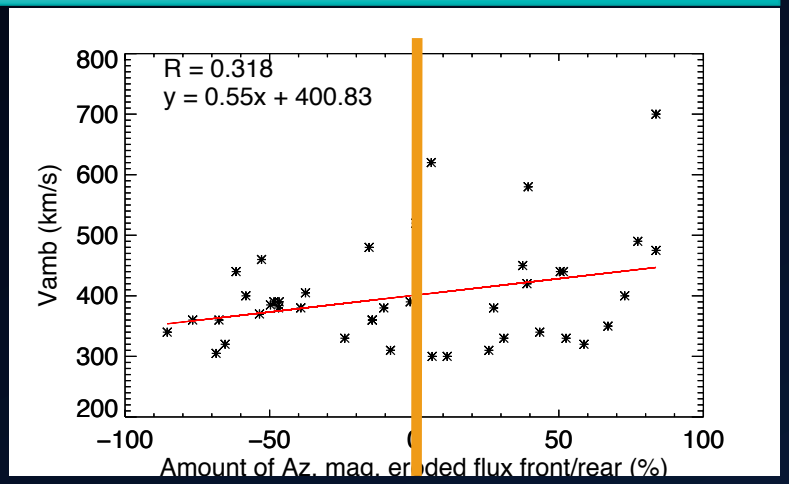
53% MCs eroded at the front



47% MCs eroded at the rear

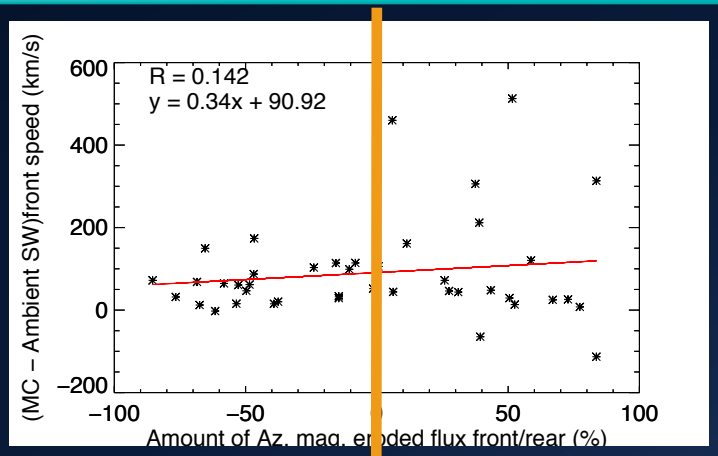
→ No correlation found between ΔV (MC mean speed – Solar Wind Speed before the front boundary) and the amount of eroded flux at the front and at the rear of the MCs

V ambient Vs. Amount of azimuthal eroded flux



Where Vamb = Solar Wind Speed before the front boundary
→ Weak correlation (R=0.3)

ΔV Vs. Amount of azimuthal eroded flux



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:**

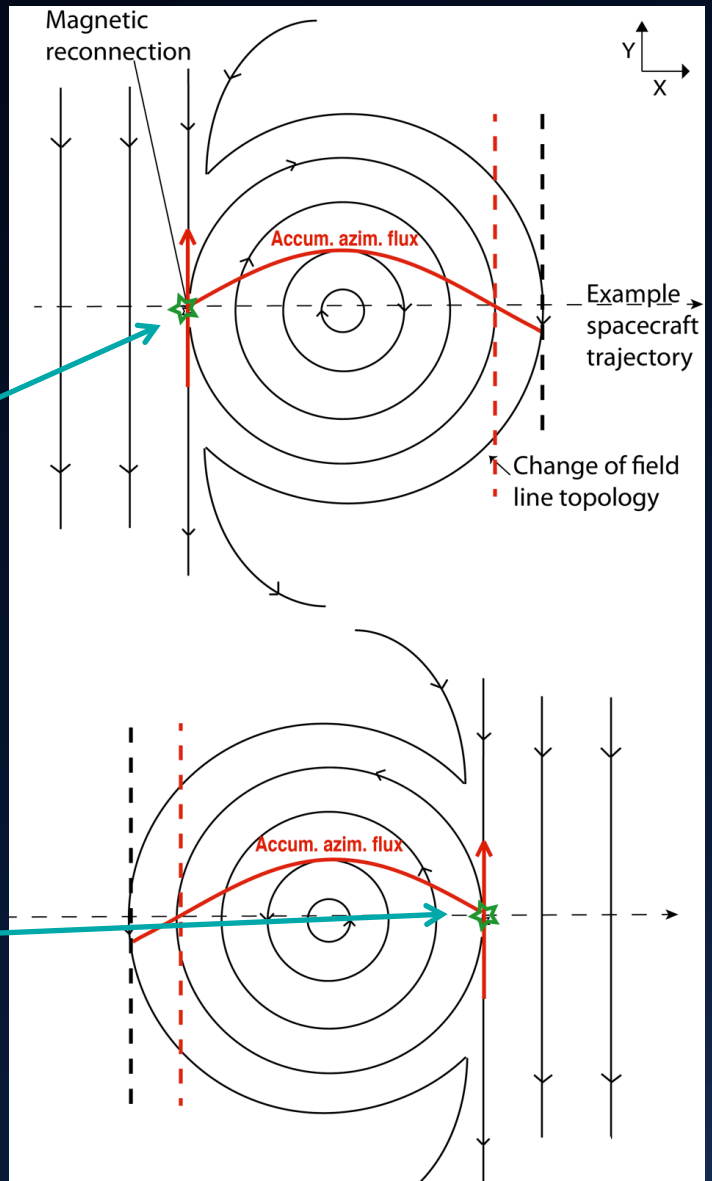
For the set of MCs where front boundaries are well localized

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**