Cassini wave observations within magnetic reconnection regions in Saturn's magnetosphere

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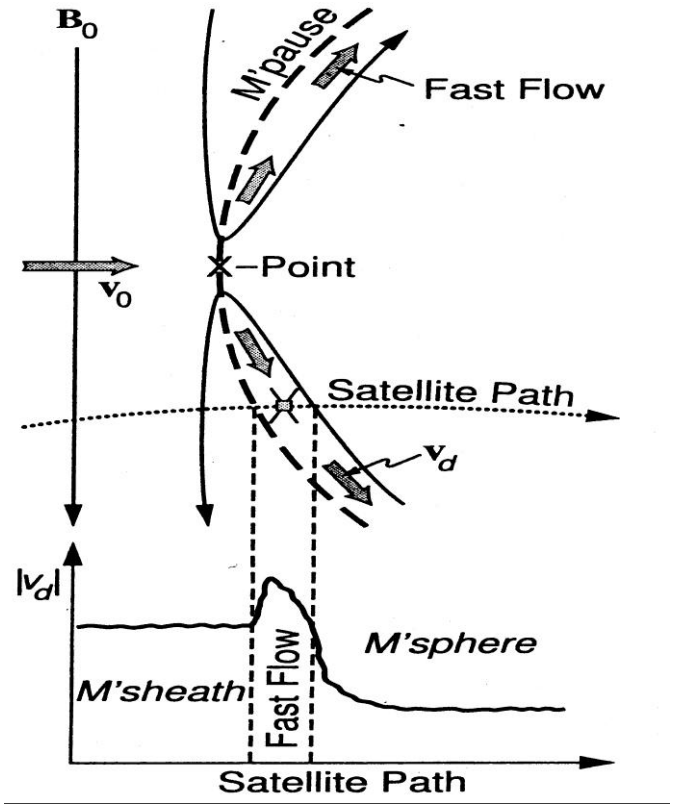
Motivation

- Magnetic reconnection major driver of mass, momentum and energy transfer in planetary magnetospheres
- Waves important proxy of reconnection dynamics however detailed observations of waves within reconnection regions are scarce in magnetospheres other than Earth's (e.g. at Saturn)
- Waves can provide evidence of reconnexion in addition to particle measurements or when particle measurements are not available
- Studying occurrence of magnetopause reconnection crucial to understand magnetospheric dynamics (e.g. Dungey's cycle vs internal dynamics)
- Studying reconnection in magnetospheres other than Earth's helps understanding dependance of reconnection properties on different plasma parameters (e.g. beta, ion composition etc.) and boundary conditions

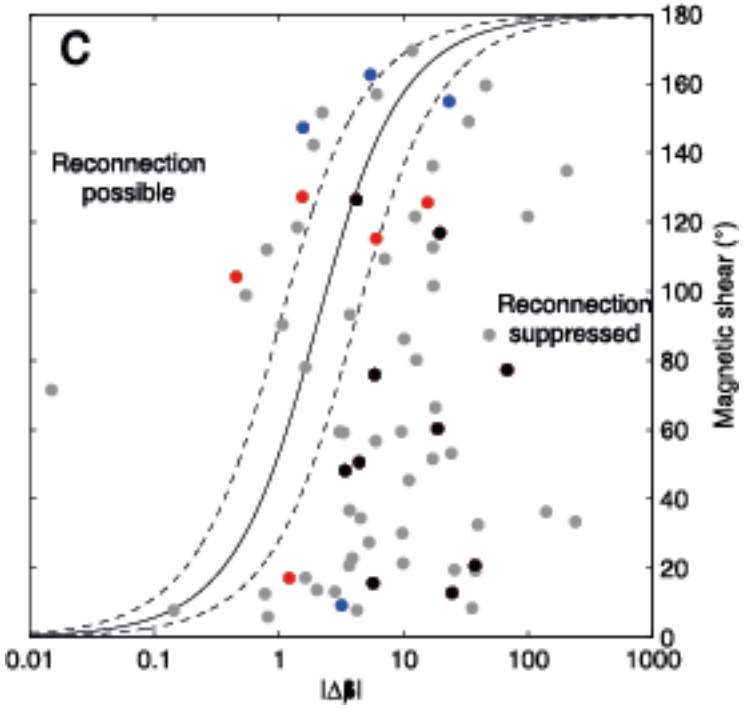
Evidence of magnetic reconnection at magnetopause from *in situ* spacecraft data



[adopted from Baumjohann & Treuman, 1996]

- **Topology change**:
  - $E_{||} \neq 0$
  - BN ≠ 0 (including FTEs)
- **Energy conversion**:
  - **plasma acceleration (jets)**
  - ion and electron heating
  - particle acceleration (non-thermal)
- **Transport**:
  - transmitted ions and electrons across MP (boundary layers)

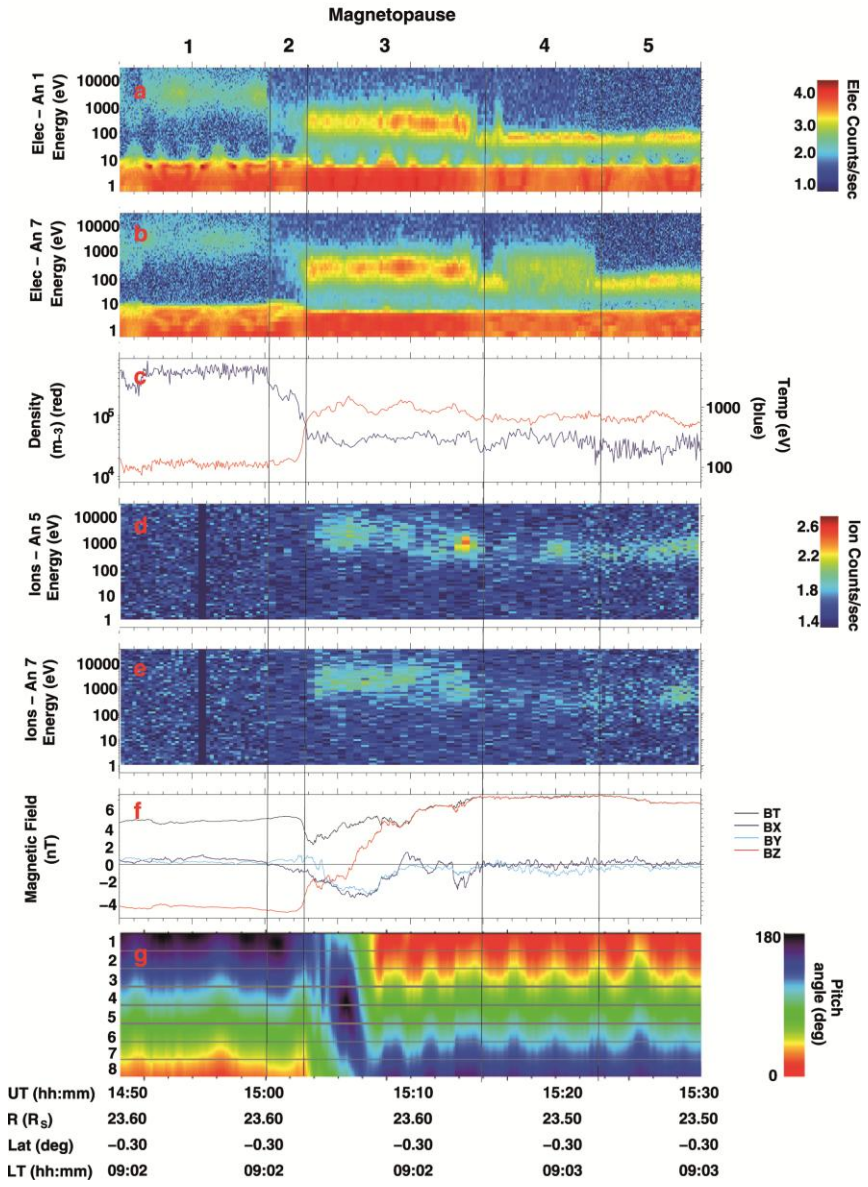
Evidence of MR at Saturn's magnetopause



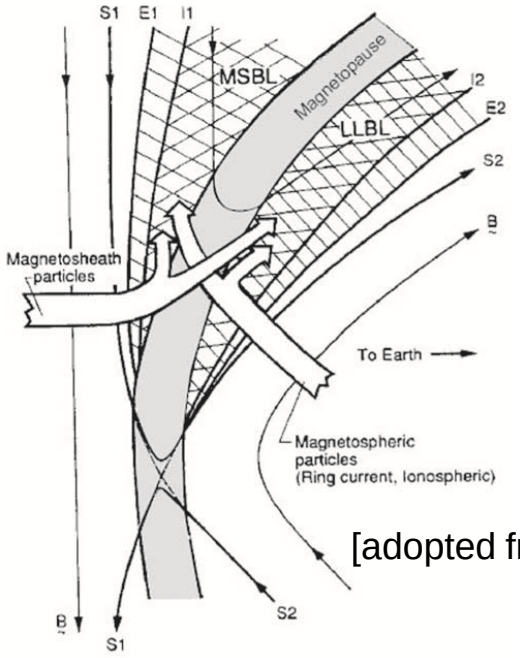
[adopted from Masters+, 2012]

- Cassini spacecraft orbits ideal to test evidence of RX (> 100s crossings)
- reconnection theoretically predicted to be infrequent at Saturn's MP (Masters+ 2012) and Dungey's cycle maybe not dominant (Masters+, 2014). However this needs to be confirmed by measurements of reconnection *in situ*
- clear evidence of RX for one case from observations of electron boundary layers [Mc Andrews+, 2008]
- lack of FTEs [Lai+, 2012] also suggests that RX is infrequent however observations based mostly on magnetic field
- remote observations of ion and electron beams for one case suggest bursty reconnection [Badman+, 2013]

Evidence of MR at Saturn's MP from ELS data



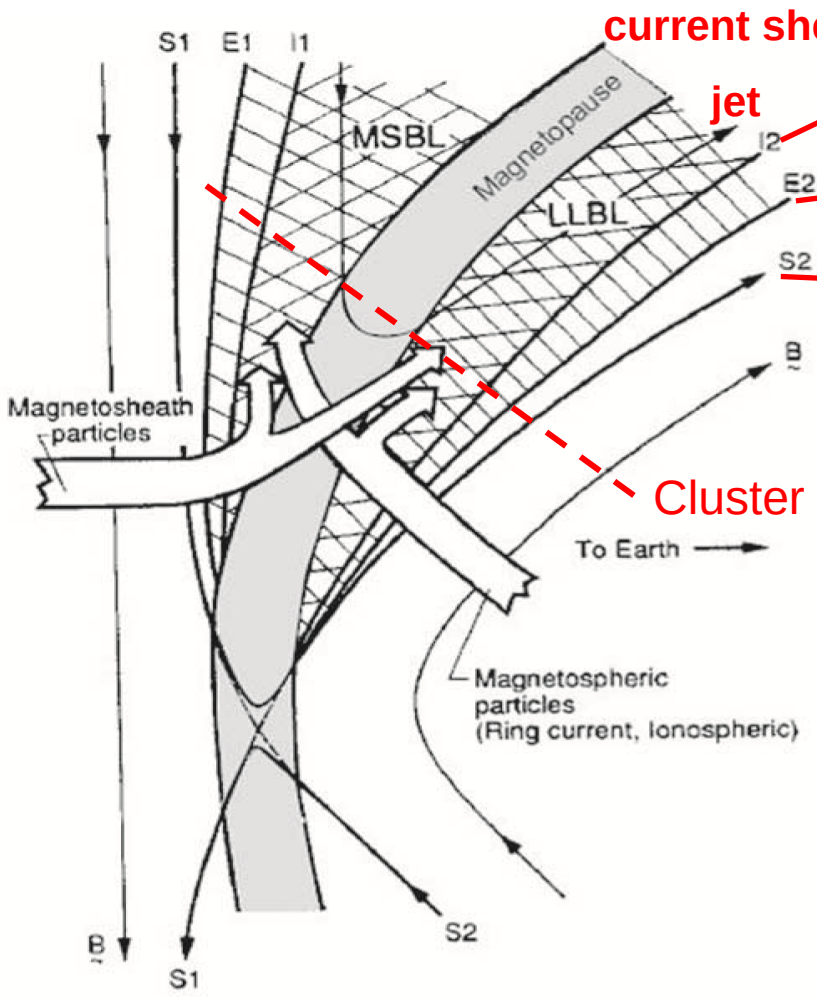
[adopted from McAndrews+,2008]



[adopted from Gosling+, 1990]

- evidence of MR based on electron boundary layers
- one case with good coverage of pitch angles by ELS
- IMS field-of-view away from reconnection jet direction
- B_N consistent with MR however magnetic field is small and errors can be large

Evidence of MR from wave measurements

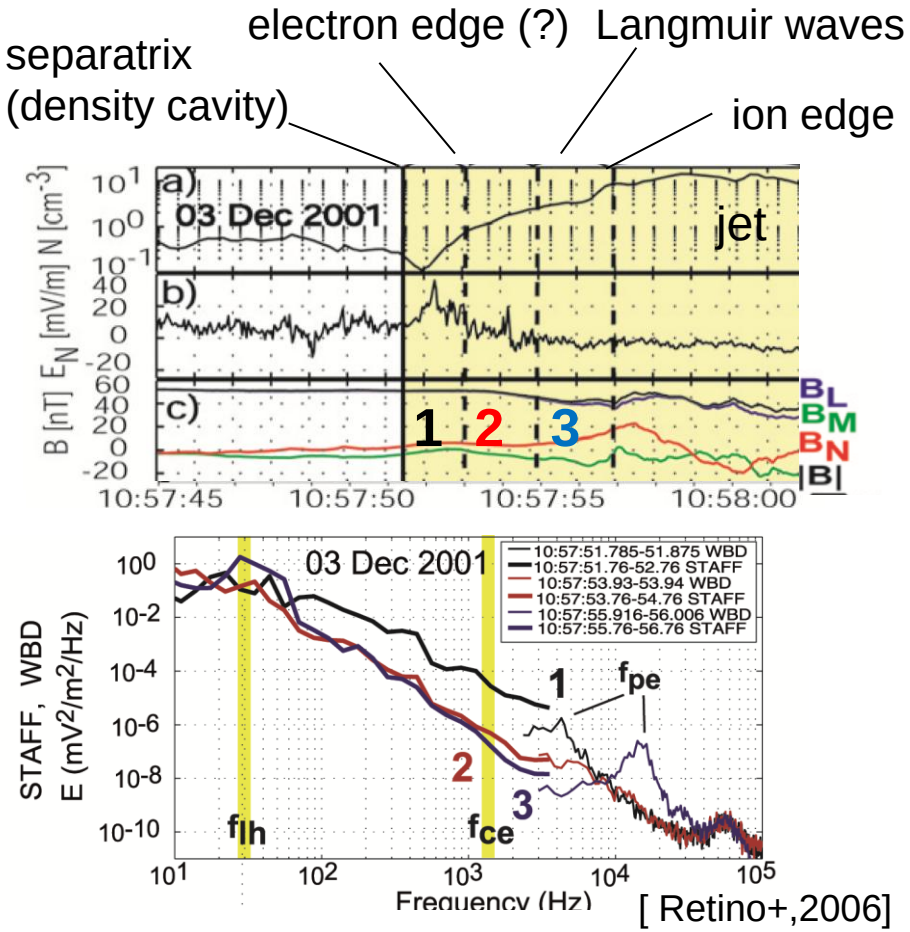


ion edge (stronger LH)

Langmuir waves (e^- beams)

electron edge (LH)

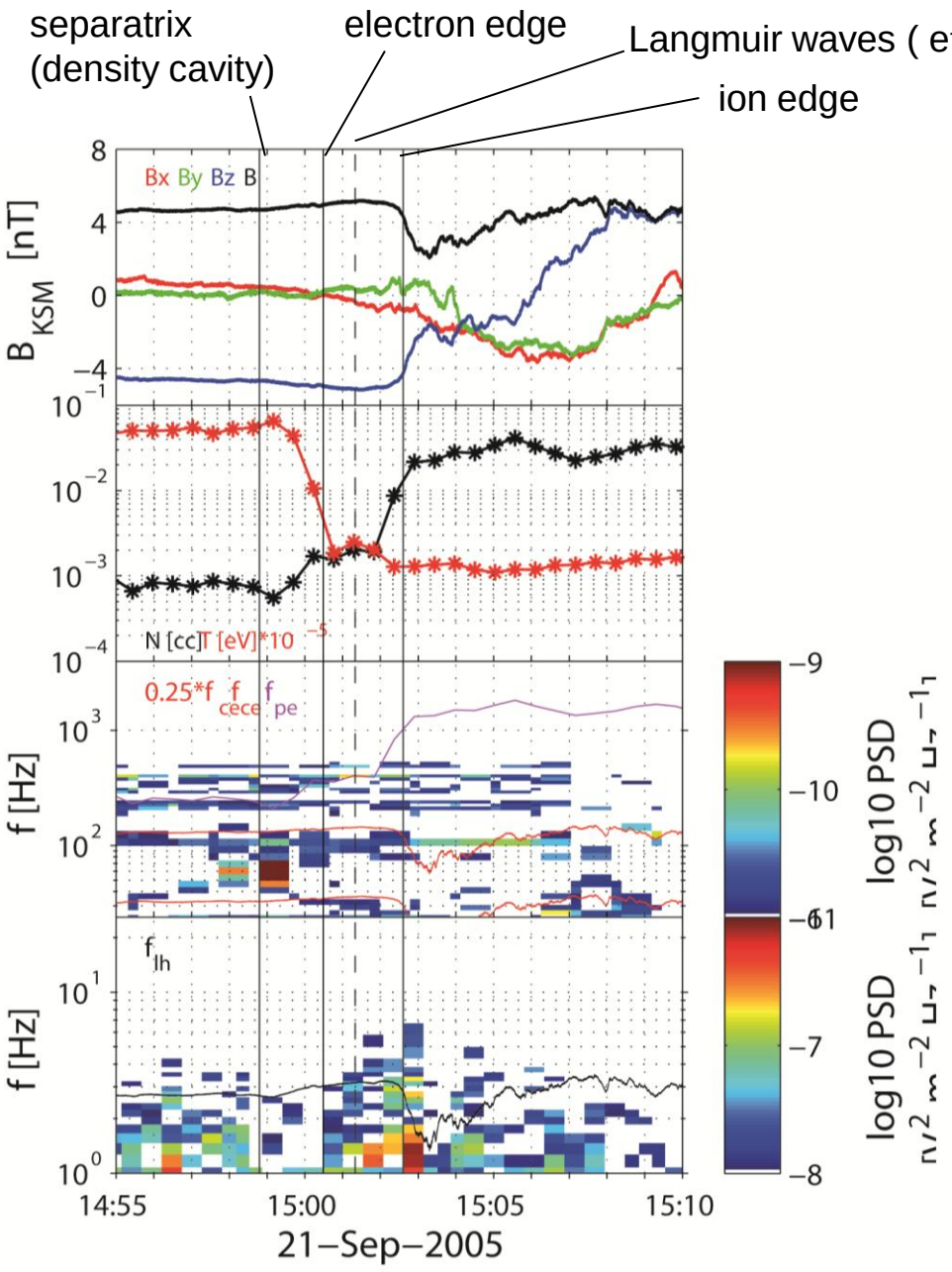
separatrix (whistlers)



[Retino+,2006]

See also Khotyaintsev+,2006; Vaivads+ 2007; Retino+,2008, Viberg+, 2013 and review by Fujimoto+, 2011

Evidence of MR at Saturn's MP from RPWS data



- wave spectra signatures on the magnetosperic side of MP

- E waves consistent with electron obs:
  - separatrix identified from boundary in whistler waves and density cavity
  - electron, ion edges identified from boundary in LH waves
  - heated electron beam in between ion/electron edge that is associated with Langmuir waves

- B waves (not shown) consistent with E (e.g. whistlers) but data are more noisy

- ion scales larger than Earth's case -> time resolution of RPWS (~ 10s s) sufficient to resolve boundaries

- waves good proxy of reconnection because (1) no FOV issue (2) continuous measurements (3) high time resolution (wrt duration of crossing)

Ongoing/future work

- analyze events with available waveforms to improve wave mode identification (e.g. whistlers as in Hospodarsky+, 2001)

- statistical analysis over the database in Masters+, 2012 to confirm theoretical prediction of low occurrence of reconnection at Saturn's magnetopause

- wave observations in the other reconnection regions in near-Saturn space (magnetotail, magnetosheath, solar wind)

Summary

- We have shown evidence of reconnection at Saturn's magnetopause from Cassini/RRWS wave spectra measurements for one single event. Wave signatures of reconnection consistent with electron measurements from ELS [McAndrews+, 2008]

- Wave signatures at Saturn's MP similar with those reported at Earth's magnetopause
  - wave boundaries are better resolved at Saturn's MP than Earth's because of larger spatial scales ☺
  - E & B simultaneous waveforms seldom available at Saturn's MP due to telemetry limitations(oppositely to Earth's case) ☹

- Our measurements suggest that waves (lower hybrid, whistlers, Langmuir) can be used as evidence of reconnection in Saturn's (and other planetary) magnetosphere in particular when plasma data are not available or have issues (FOV, low time resolution)

- Cassini RPWS observations also suggest improvements necessary for similar measurements with future planetary missions e.g. by ESA/JUICE:
  - higher quality of low frequency measurements in particular for search coil magnetometer (SCM mounted on boom at >3m distance from spacecraft onboard JUICE ☺)
  - better identification/removal of interferences in low frequency range
  - increase of E&B waveforms coverage at boundaries (e.g. Ganymede's magnetopause)