MMS and Van Allen Probes conjunctions: Studying wave activity associated with energetic particle injections and substorms

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NASA’s Magnetospheric Multiscale (MMS) Overview

- Launched March 2015
- 4 identical s/c in close formation (10s to 100s km separation)
- Currently in 24-hr elliptical orbits (apogee ~12 Re)
- Precession around the system in 1-year
- Full suite of plasma, particles, fields, and waves instrumentation

Fig. 4 MMS instrument deck layout

Table 1

Major instrument suite elements and responsible co-investigators

<table>
<thead>
<tr>
<th>Instrument Suite</th>
<th>Responsible Co-investigator</th>
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</thead>
<tbody>
<tr>
<td>FIELDS</td>
<td>Roy Torbert—UNH</td>
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<tr>
<td>Fast Plasma</td>
<td>Craig Pollock—GSFC</td>
</tr>
<tr>
<td>Energetic Particles</td>
<td>Barry Mauk—APL</td>
</tr>
<tr>
<td>HPCA</td>
<td>Stephen Fuselier—SwRI</td>
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</tbody>
</table>

ADP - Axial Double Probe
AFG - Analog Flux Gate Magnetometer (mounted on boom)
ASPOC - Active Spacecraft Potential Control
CEB - Central Electronics Box (Fields)
CIDP - Central Instrument Data Processor
DES - Dual Electron Spectrometer
DFG - Digital Flux Gate Magnetometer (mounted on boom)
DIS - Dual Ion Spectrometer
EDI/GDU - Electron Drift Instrument/Gun Detector Unit
EIS - Energetic Ion Spectrometer
FEEPS - Fly’s Eye Energetic Particle Sensors
HPCA - Hot Plasma Composition Analyzer
IDPU - Instrument Data Processing Unit (FPI)
SCM - Search-Coil Magnetometer (mounted on boom)
SDP - Spin-Plane Double Probe
TP/HPDB – Test Panel Heater Power Distribution Box

Burch et al. [SSR 2015]
NASA’s Magnetospheric Multiscale (MMS)

**MMS Instrument Details**

**FPI:**
- Ions: eV to 30 keV, 150 ms all-sky dist. and moments
- Electrons: eV to 30 keV, 30 ms all-sky dist. and moments

**HPCA:**
- Ion composition (10 eV to 30 keV)
- H⁺, He⁺, He++ + O⁺
- Full distributions every spin

**EPD:**
- EIS
- FEEPS

**FEEPS:** Flys Eye Energetic Particles Sensor
- Electron spectra: Nine views/head
  25 – 500 keV
- Ion spectra (total ions): Three views/head
  45 – 500 keV

**EPD:**
- EIS
- FEEPS

**FIELDS:**
- 3D E-fields: DC to 100 kHz
- 3D B-fields
  - FGM: DC to 64 Hz
  - SCM: 1 Hz to 6 kHz
- EDI for E-field and MAG cal

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Torbert et al. [SSR 2014]
Mauk et al. [SSR 2014]
MMS Phase 1x

Opportune period for conjunctions with Van Allen Probes

Phase 1x start: 08 Mar 2016

Phase 1x end: 26 Sep 2016
MMS/Van Allen Probes Superconjunction: 01 May 2016

All 6 spacecraft within $0.4 R_E$ around ~23:00 UT

- Burst data from MMS available
- Wave burst data on RBSP available

Allison Jaynes is leading analysis on this event
MMS/Van Allen Probes Superconjunction: 01 May 2016

Chorus waves: evolution and effects

MMS

• Differences seen between 4 MMS spacecraft

Van Allen Probes

• Chorus falls below 0.1 $f_{ce}$ part of the time
• Slight differences between wave spectra on RBSP A & B
• Nice modulation of chorus

Much to study during this event!
• Modulation of VLF by ULF
• Chorus evolution in space and time
• Particle effects

More results at AGU

Similar to observations in Jaynes et al. [2015] and Chen et al. [2016]
07 April 2016 Conjunction

Event orientation

- Conjunction between RBSP-B and MMS (all 4 s/c) around 01:45UT on 07 April 2016
- Occurred on dawn side around 06:30 LT
- Min. distance between ~1.15 RE
07 April 2016 Conjunction
Magnetic conjunction: ~02:05 UT

- Tsyganenko-Sitnov [2005] model indicates magnetic conjunction (closest in L-shell and MLT) is at ~02:05 UT

- Closest physical approach is much earlier, around ~01:45 UT

- Both RBSP and MMS are at higher latitude

- Note, MMS at higher latitude than RBSP
07 April 2016 Conjunction

**MMS Configuration**

- MMS separated by 10s of km
- Not an ideal tetrahedron configuration but it will still work well for 3D propagation of physical features (e.g., wave fronts)
Solar Wind Data
OMNI 5-min

- Nothing special…. at all!
  - Bz persistently southward but weak
  - Lower than average speed
  - Density high but pressure normal
  - Density and pressure spike (weak) at 00:50 – 01:30 UT
  - Minor substorm activity from AE and AL between 01:00 and 02:30 UT
  - Non-storm period from SYM-H
07 April 2016

**Electron Injections**

- RBSP-A: Observed 3 dispersed injection signatures
- RBSP-B: Observed 1 (or 2?) clear dispersed injection signature
- MMS: Observed 3+ dispersed injection signatures; 3rd injection has clear substructure or is really a close series of injections
- RBSP sees no such substructure...
07 April 2016

Electron injections

• LANL-GEO data:

• “Drifting electron holes” → have to do with insufficient source population in plasma sheet

• As Geoff said: “The plot thickens…”

Near-dispersionless (and dispersed or echo?)

At least 1 dispersed

At least 4 dispersed

1 dispersed
MMS Electrons

FEEPS Burst Data

- MMS-FEEPS PADs: in burst mode, we have 0.3 sec resolution!

- Different arrival timing between spacecraft? No... Electrons are drifting (and gyrating) too fast

- Pitch angle dispersion is very clear though
MMS Electrons
FEEPS Burst Data

- Substructure much clearer here: at least 4 injections...

- Upper energy cutoff steps up with each new injection [e.g., Turner et al., GRL 2016]
07 April 2016

Ion injections

- Ion injections observed by Geotail and MMS but not by RBSP!

Electron injections penetrated to lower L-shells than the ion injections!
ULF Waves
Wave activity observed during injections

- ULF wave activity observed by all three s/c
- Waves occur around the same time as the injections are observed
- Periods are different at different spacecraft
- Note scales different on wave plots...
ULF Waves

Analysis

- These are large-scale, toroidal field line resonances!
- The waves were present prior to the injections
- Different frequencies at different s/c is a spatial effect: FLR frequencies decrease with increasing L (longer field lines)

Conclusion: These are ongoing field line resonances (FLR); though interesting, they are likely not directly related to the injections
Chorus Waves

*Wave activity observed during injections*

- Chorus wave activity lights up when <50 keV electrons from the injection drift past the spacecraft
- Need to look at HOPE data from RB
- NO FPI from MMS... 😞
Chorus Waves

*RBSP Analysis*

- Definitely some correspondence between $\leq 33$ keV electrons and chorus waves
- High resolution PAD data from RBSP-A shown here (binned at 1-deg in PA)
Chorus Waves

*MMS Analysis*

- Multipoint observations from MMS
Chorus Waves

MMS Analysis

- Need E-field data in GSE (currently just in instrument coordinate frame)

- With that, can start looking at Poynting flux, wave-vectors, and how these waves are propagating and evolving as they do so…
Chorus Waves

MMS Analysis

- Note phase: this is clearly the same wave observed by all four MMS spacecraft.

- Note also difference in amplitudes...