Relationship between MMS Science Objectives, SMART Instrument Performance, and Data Products

Science Objectives

Generalized Ohm's Law: $en_e(\mathbf{E} + \mathbf{v} \times \mathbf{B}) = m_e n_e d\mathbf{v}_e/dt - \nabla \cdot \mathbf{p}_e + \mathbf{J} \times \mathbf{B} + \eta e n_e \mathbf{J}$

	RECONNECTION				TURBULENCE		PARTICLE ACCELERATION	
Phenomenon	Electron inertia	Divergence of non-gyrotropic electron pressure tensor	Hall effect	Anomalous resistivity	MHD turbulence	Kinetic turbulence	Inductive electric fields	Reconnection electric field
Scale Size	Electron skin depth: 5 $n^{1/2}$ km	Electron skin depth: 5 $n^{1/2}$ km	Ion skin depth: 250 $n^{1/2}$ km	Ion skin depth: 250 $n^{1/2}$ km	Ion dissipation: (skin depth)	Ion dissipation: (skin depth)	100s of km to 1 R_E	Ion and electron skin depths
Primary Measurements	Electron distribution function; **E**-field; J-parallel	Electron moments at 4 points; low-frequency EM waves, **E**-field	Ion distribution function; whistler-mode turbulence; electron currents; E-perpendicular; **B** at 4 points	EM turbulence	Resolve MHD waves at the dissipative scale propagating at the Alfvén speed (<1000 km s^{-1}) in plasma density, velocity, and B	Ion distribution function; EM turbulence; electron current; E-perpendicular	**E** and δ**B**/δt using 4-point measurements; electron and ion distribution functions from 1 - 1000 keV	**E** and δ**B**/δt ; electron and ion distribution functions from 100 eV to 20 keV; E and B wave spectra
Time Resolution*	8 ms	8 ms	400 ms	433 ms	100 ms	400 ms	5 s	30 ms (plasma electrons) 400 ms (plasma ions) 5 s (energetic particles)

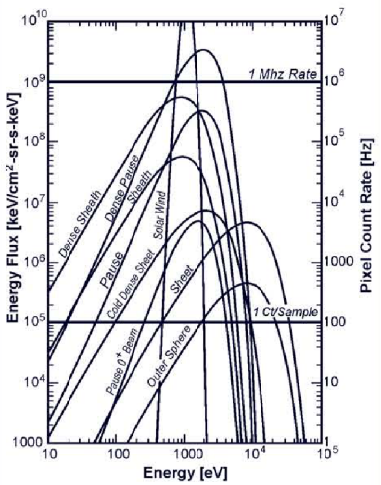
*assuming n = 10 cm^{-3}, B = 30 nT, magnetopause velocity = 20 km s^{-1}, with five samples across each region

Adapted from Burch and Lewis [1998]

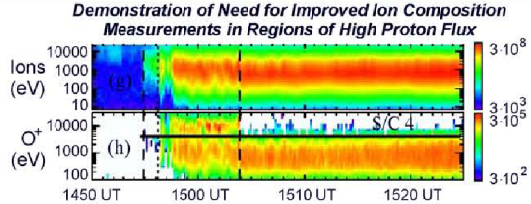
Instrument Performance

PLASMA ELECTRONS	PLASMA IONS	PLASMA COMPOSITION	ENERGETIC PARTICLES	ENERGETIC PARTICLE COMPOSITION	WAVE ELECTRIC FIELD	WAVE MAGNETIC FIELD	DC ELECTRIC FIELD	DC MAGNETIC FIELD
G = $3 \cdot 10^{-4}$ cm^2 sr eV/eV (pixel geometric factor) Energy: 1 eV-30 keV ΔE/E=17% Time Resolution: 5 ms (coarse), 30 ms (fine)	G = 110^{-3} cm^2 sr eV/eV (pixel geometric factor) Energy: 1 eV-40 keV ΔE/E=17% Time Resolution: 250 ms	G = 210^{-3} cm^2 sr eV/eV (pixel geometric factor) Energy: 1 eV-40 keV ΔE/E=17%; M/ΔM=4 (1%) Time Resolution: 6 s	G = 0.1 cm^2 sr (per pixel) Simultaneous multi-directional views Energy: 20-1000 keV (electrons) 40-1000 keV (ions) Time Resolution: 3 s	G = 0.01 cm^2 sr (per pixel) Energy: 10-1000 keV ΔE/E = 45% Mass Separation: H^+, O^+ Time Resolution: 12 s	Sensitivity = 2×10^{-7} V/m-$Hz^{1/2}$ Freq. Range: 10-100 kHz	Sensitivity = 2×10^{-5} nT/$Hz^{1/2}$ Freq. Range: 0-10 kHz	Accuracy = 0.3 mV/m (spin plane) 0.5 mV/m (spin axis) Time Resolution: 1 ms/sample	Accuracy = 0.1 nT (three-axis) Time Resolution: 10 ms/sample

Basis for Ion Instrument Geometric Factors Showing Expected Count Rates for Composition Instrument

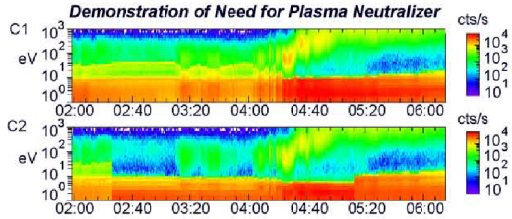


Demonstration of Need for Improved Ion Composition Measurements in Regions of High Proton Flux



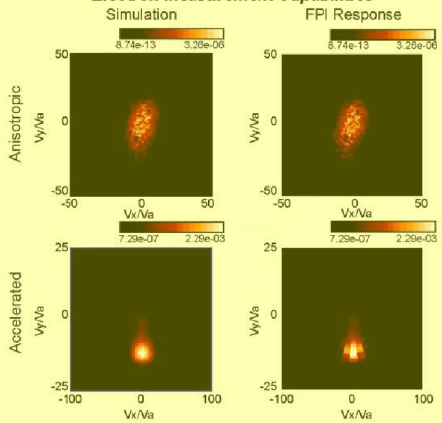
Cluster Ion Data. All O^+ fluxes below the black bar are actually contamination from the high proton fluxes [from Phan et al., 2003].

Demonstration of Need for Plasma Neutralizer



Cluster Electron Data. ASPOC is off in top panel where the thin yellow line in spectrogram shows s/c potentials up to 40 V. ASPOC is on after 02:27 in bottom panel allowing structured electron distributions to be measured at energies below a few hundred eV [from Szita et al., 2001].

Demonstration of Diffusion Region Electron Measurement Capabilities

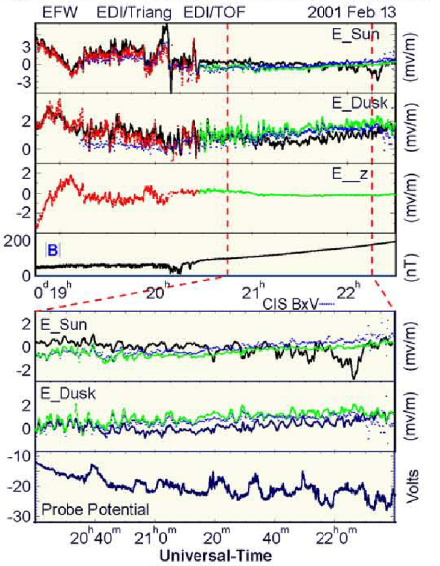


Comparison of simulated electron distributions (left panels) with measurements of them by the SMART Fast Plasma Instrument (right panels). Upper panels: a nongyrotropic electron distribution function at the edge of the electron region. Lower panels: an electron distribution function with a tail produced by parallel electric field acceleration in the centrl reconnection region.

The SMART instrument package addresses the MMS science objectives with four unparalleled advances:

- The electron and ion analyzers have unprecedented time resolution (8 ms) needed to explore the electron diffusion region. The addition of a plasma neutralizer allows measurement of complete plasma distribution functions in all orbital environments.
- The electric field measurement combines the electron drift instrument (EDI) with a 3-axis double probe, providing an accuracy of better than 0.1 mV/m and full bandwidth coverage. Parallel electric fields can be verified since the EDI and double probes always share a common axis. Cluster has clearly demonstrated that a double probe alone cannot meet the MMS challenge.
- The SMART ion composition instrument will separate ion species with extraordinary accuracy. The radio-frequency technology in the hot composition plasma analyzer will overcome past difficulties of H^+ contamination in the O^+ measurement and thus, for the first time, establish an accurate pressure at critical boundaries and determine the origin of plasmas.
- The energetic particle detectors will provide 3D distributions with unprecedented sensitivity and speed along with critical mass separation.
- Two magnetometers with independent in-flight calibration using the EDI will determine the current sheet normal direction with unprecedented accuracy.

Demonstration of Need for Electron Drift Instrument



Cluster at an inbound magnetopause crossing. **E**-field measurements often show differences between the Double Probe (EFW) and EDI that change with plasma conditions, as reflected in the probe potential. Despite general EFW-EDI agreement overall, data from the plasma composition instrument (CIS, blue dots in the expanded interval below) show that EDI agrees more closely with -**vxB**. Both EDI and the Double Probe are needed for precise 3D **E**-field measurements in reconnection regions and to properly interpret measurements where plasma parameters vary rapidly.

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