Spacecraft Potential Control for the NASA Magnetospheric Multiscale (MMS) Mission

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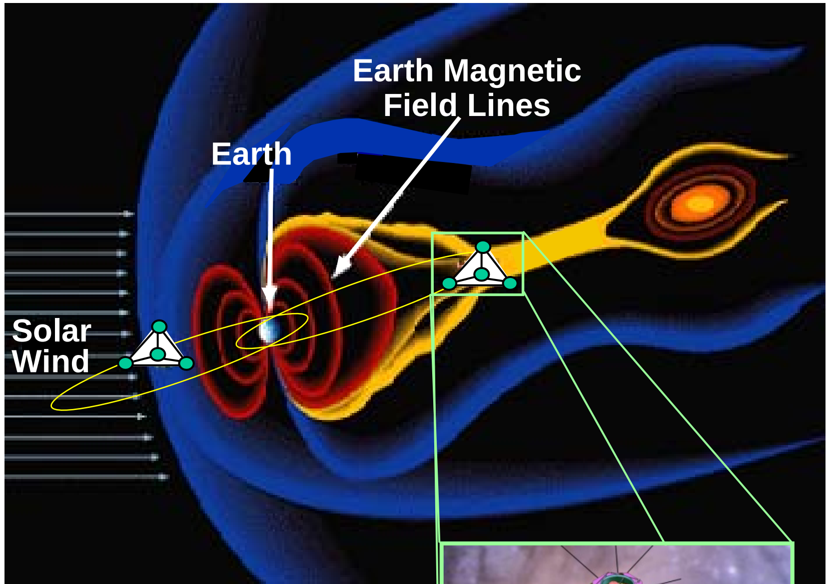
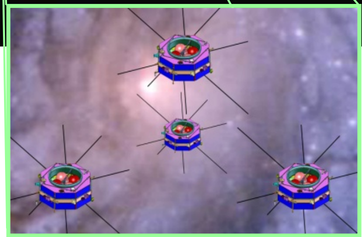
MMS Overview





Mission Team

NASA SMD

Southwest Research Inst.
- Science Leadership
- Instrument Suite
- Science Operations Control Center
- Science Data Processing

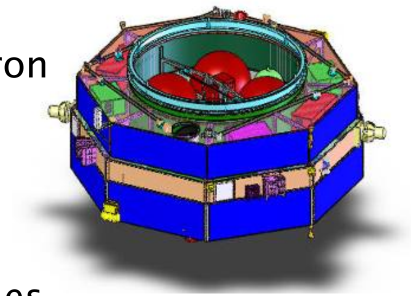
NASA GSFC
- Project Management
- Mission System Engineering
- Spacecraft
- Mission Operations Control Center

NASA KSC
- Launch services

Science Objectives

Discover the fundamental plasma physics process of reconnection in the Earth's magnetosphere
- Temporal scales of milliseconds to seconds
- Spatial scales of 10s to 100s of km

Mission Description



4 identical satellites, tetrahedron separation as close as 10km

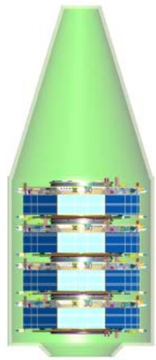
2 year operational mission

launch in 2014

Orbits

Elliptical Earth orbits in 2 phases
- Phase 1 day side of magnetic field 1.2 R_E by 12 R_E
- Phase 2 night side of magnetic field 1.2 R_E by 25 R_E

Instruments



Identical *in situ* instruments on each satellite measure
- Electric and magnetic fields
- Fast plasma with composition
- Energetic particles
- Hot plasma composition

Spacecraft

- Spin stabilized at 3 RPM
- Magnetic and electrostatic cleanliness

Launch vehicle

4 satellites launched together in one Atlas V

MMS Top Measurement Requirements

Sample Regions of Primary Scientific Interest for Reconnection at the Dayside Magnetopause and the Nightside Neutral Sheet throughout the 24-Months of Prime Mission Operation (80-100 Encounters Anticipated)

From Four Spacecraft

Vector DC Magnetic Field
- *Accuracy 0.1 nT*
- *Time Resolution 10 ms*

Vector DC Electric Field
- *Accuracy 0.5 mV/m*
- *Time Resolution 1 ms*

Plasma Waves
- *Electric Vector to 100 kHz*
- *Magnetic Vector to 6kHz*

3D Plasma Electron Distribution to 30 keV
- *Time Resolution to 30ms*

3D Plasma Ion Distribution to 30 keV
- *Time Resolution to 150ms*

From at Least Three Spacecraft

3D Plasma Composition to 30keV
- *Time Resolution 15 s*

3D Electrons and Ions to 500 keV
- *Time Resolution to 10 s*

3D Ion Composition to 500 keV
- *Time Resolution to 30 s*

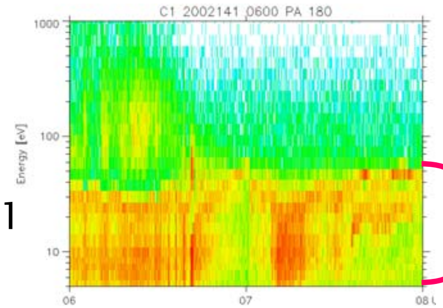
By controlling the spacecraft potential, ASPOC enhances the quality of these measurements

Science Goals

- ASPOC shall reduce the spacecraft potential
  - to allow complete measurements of the plasma electron and ion distribution functions (including the cold population), which are essential to understand complex plasma processes

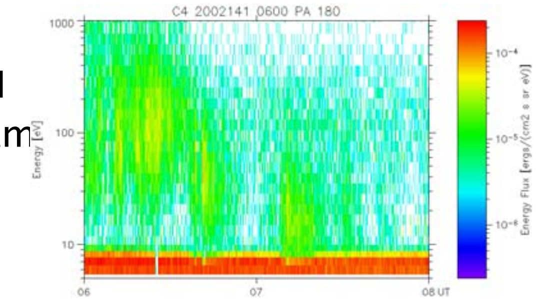
Electrons
Cluster 1
ASPOC OFF

2002-05-21



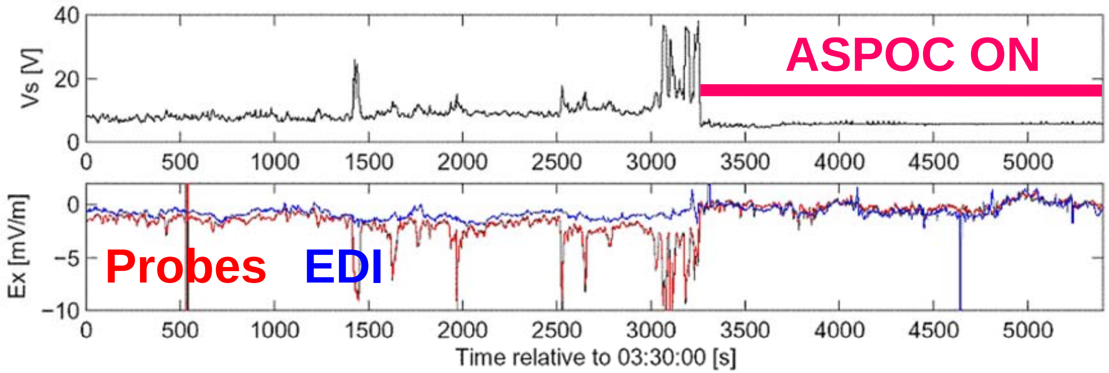
Disturbing photo-electrons

Cluster 4
ASPOC ON
10 μA beam



- to allow accurate electric field measurements

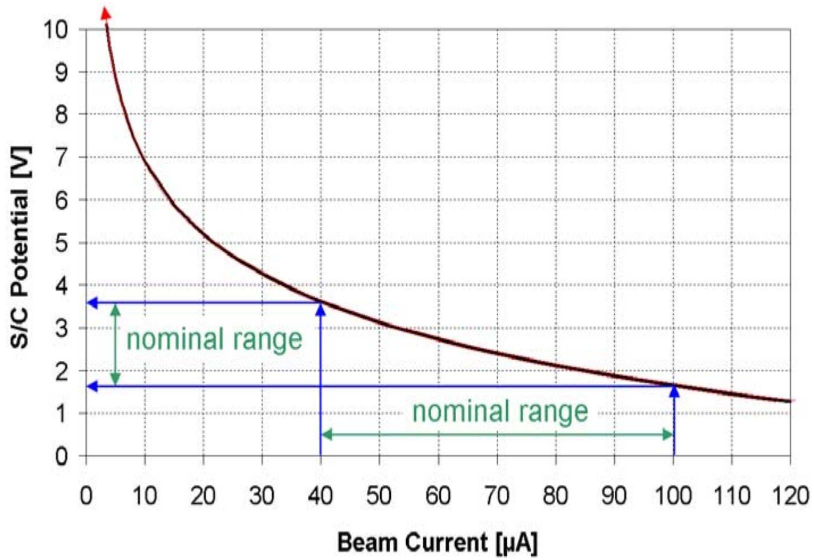
Cluster 3
2001-02-14, 0330-0500



Science Requirements and Flow-Down

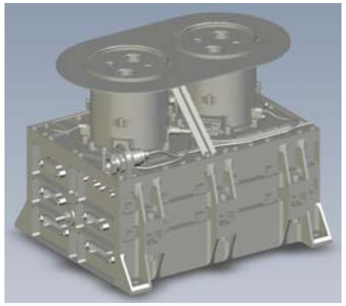
Science Requirements	▪ Generate beams of positive ions to limit positive spacecraft potentials to +4V (target: +2V) in order to improve the measurements obtained by FPI, HPCA, ADP, and SDP ▪ For measurements by FPI, HPCA, ADP, SDP see respective sections
Instrument Requirements	▪ Generate ion beams with nominal currents up to 20 µA per instrument (40 µA per spacecraft) ▪ Generate ion beams with currents up to 50 µA per instrument (100 µA per spacecraft) for limited time

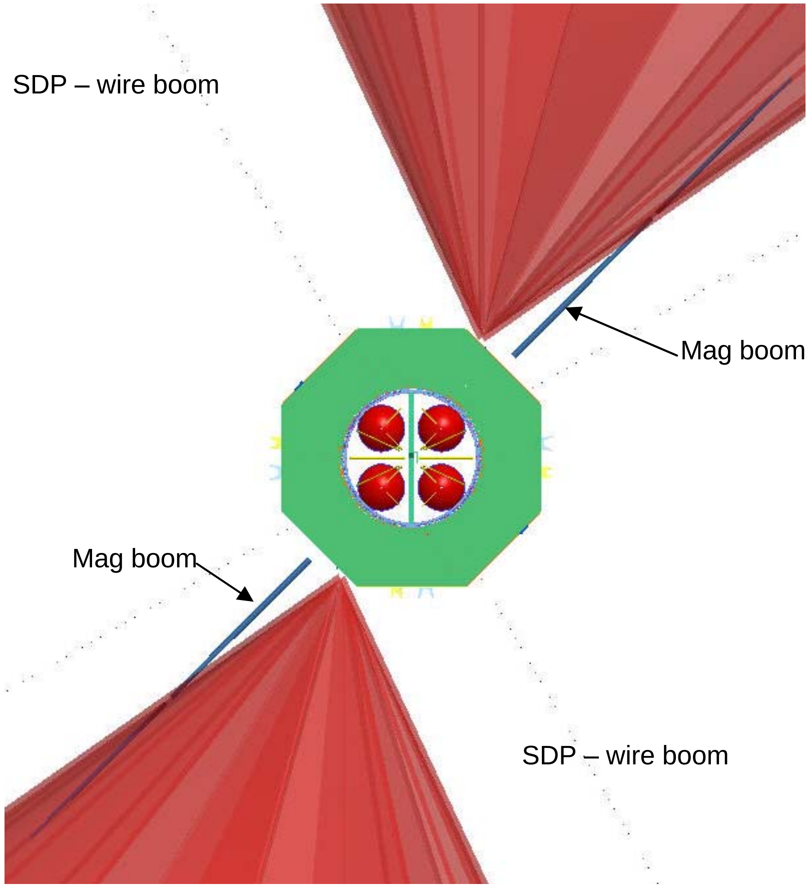
- Cluster: good plasma measurements with $V_{spacecraft} < 10V$
- MMS: ion currents of 40...100 µA per spacecraft will result in ~3.6 to ~1.6 $V_{spacecraft}$
- Exact relation between current and potential depends on s/c size, shape, surface material, and solar activity



Configuration

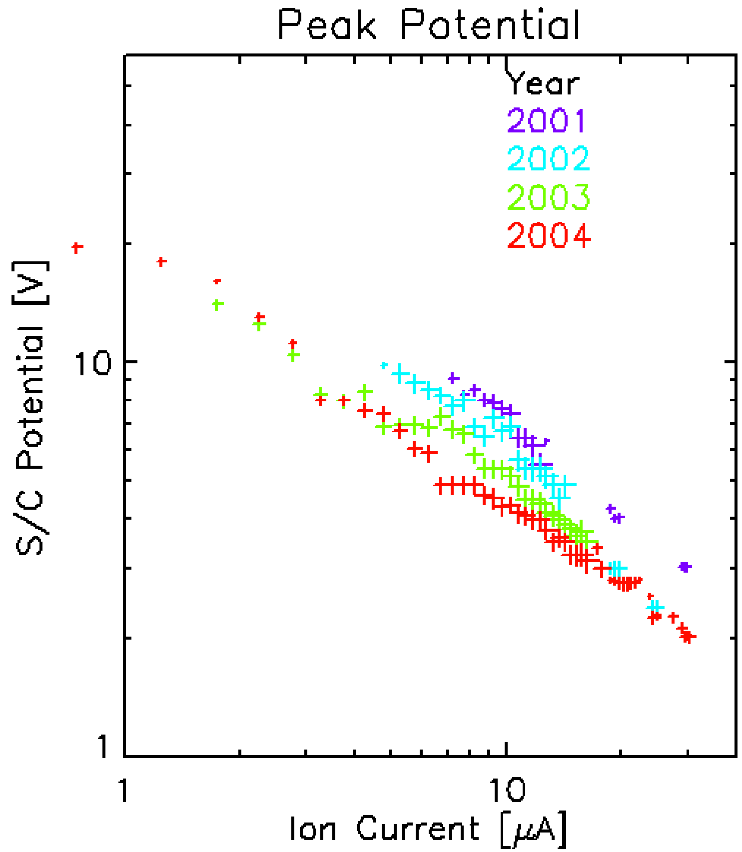
- ASPOC's installed at opposite sides of the s/c
- Emit antiparallel ion beams into the spin plane



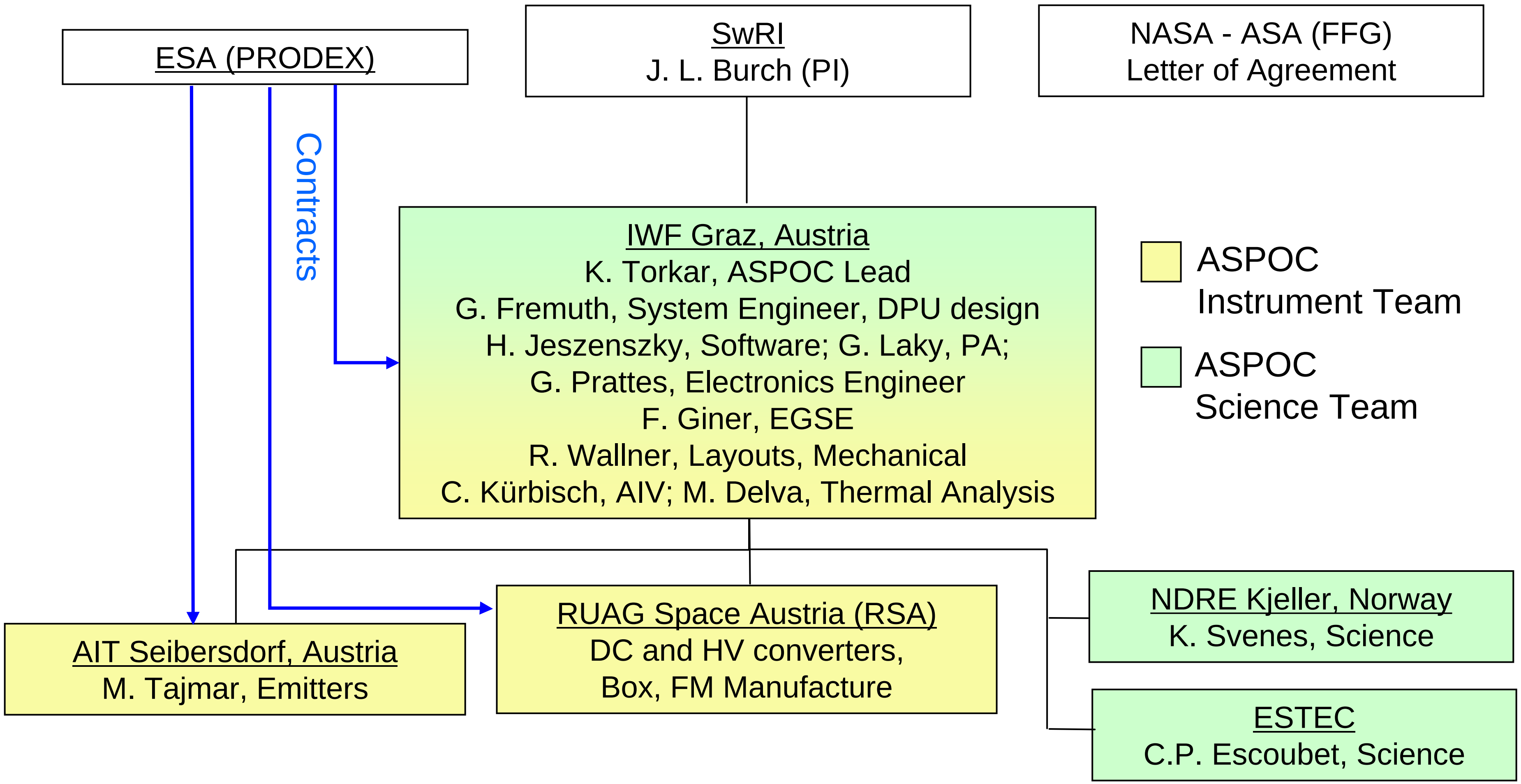


Spacecraft Potential vs. Beam Current

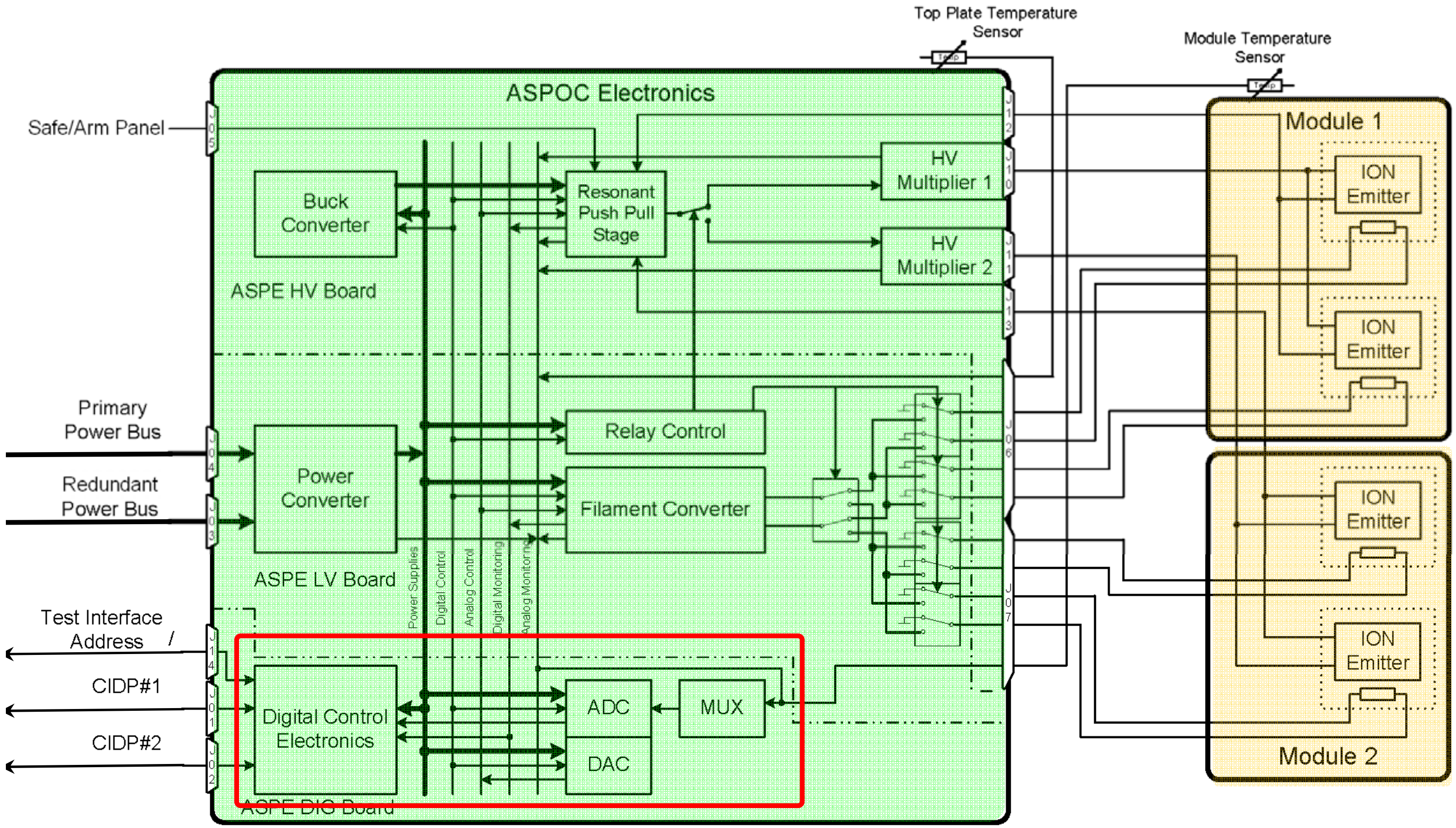
- Torkar et al. (2008) found a decreasing trend of Cluster spacecraft potential in a period of decrasing solar activity.
- Solar activity in 2014/2015 not be in solar max.
- Conditions similar or less active than in 2004 expected for MMS
- As Cluster spacecraft are of similar size as the MMS spacecraft, a similar relation between beam current and potential is expected.



ASPOC Team Organization



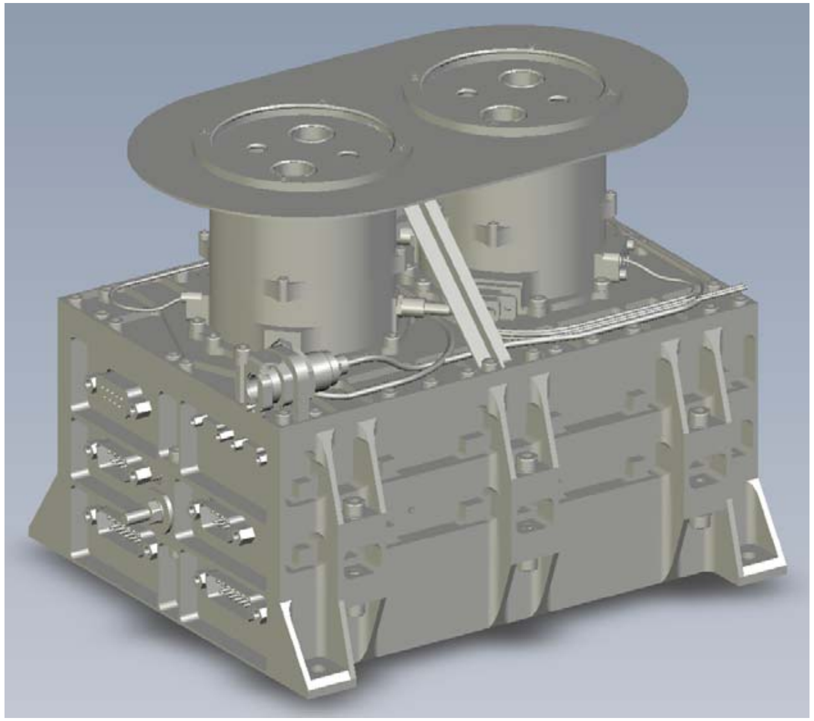
ASPOC Block Diagram



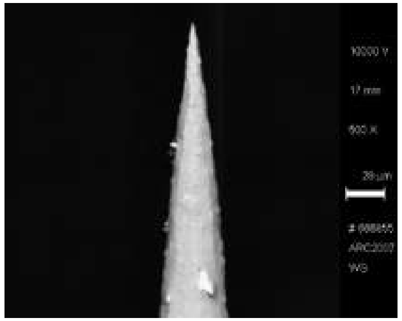
- Single box with 3 electronics boards and two pairs of ion emitters, each pair with common high voltage circuit
- Responsibilities shared between IWF, RSA, and AIT

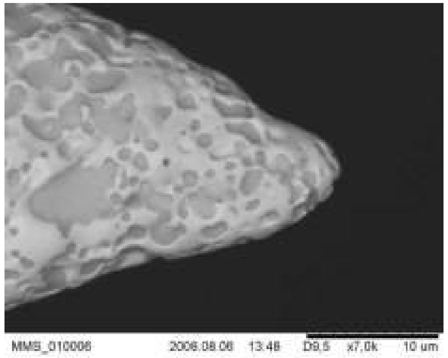
ASPOC Hardware Summary

- Two instruments per spacecraft
- Each instrument contains four liquid metal (Indium) ion sources
  - operated in sequence
  - operating voltage 4 – 10 kV
  - maximum current capability: 70 μA
  - typical current: 20 μA
- Electronics consists of:
  - two high voltage multipliers
  - low voltage power converters
  - emitter heater power converters
  - digital electronics
- Mass / unit: 2.9 kg
  - includes radiation shield mass
- Power / unit (nominal): 4.6 W



Emitter Technology at AIT

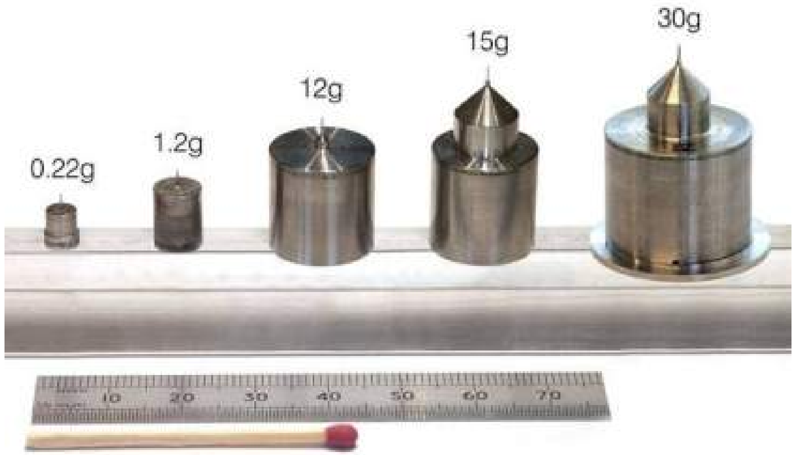




Needle Emitters (Tungsten, Tantalum, Zirkonium, Tungsten Skin)

Porous Tungsten Emitters

Capillary Emitters (Steel, Tantalum, Sharpened)



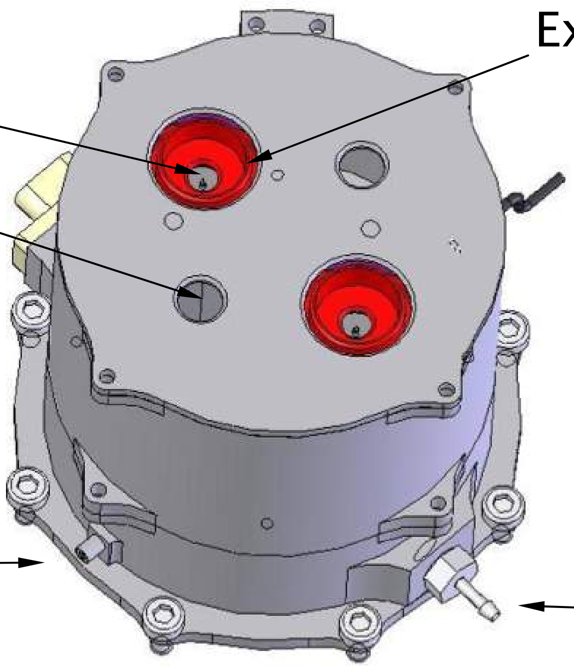
Emitter Selection

	Requirement	Tantalum Capillary
Ion Beam Performance	5-100 µA	Very good stability along the whole ion current range
Field-of-View	< 45°	< 45° per design
Nominal Voltage	4-10 kV, ignition < 8kV, operating < 7kV	Ignition is typically < 7 kV, operating voltage is between 5.5 and 7 kV
HV Power Consumption	< 0.65 W	0.34 W @ 50 µA
Lifetime	5300 h	>7576 h

→ Selection of Tantalum Capillary with Sharp Tip due to High Reliability

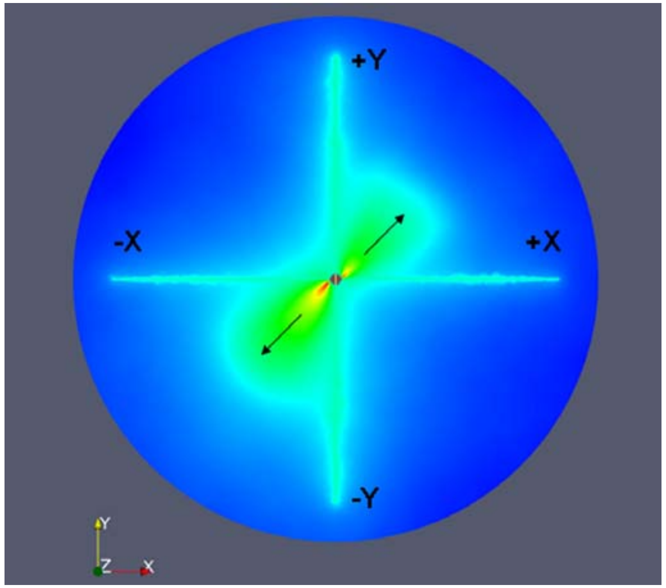
Due to the use of tantalum – no indium contamination and exceptional stable performance compared to old capillary design (stainless steel)

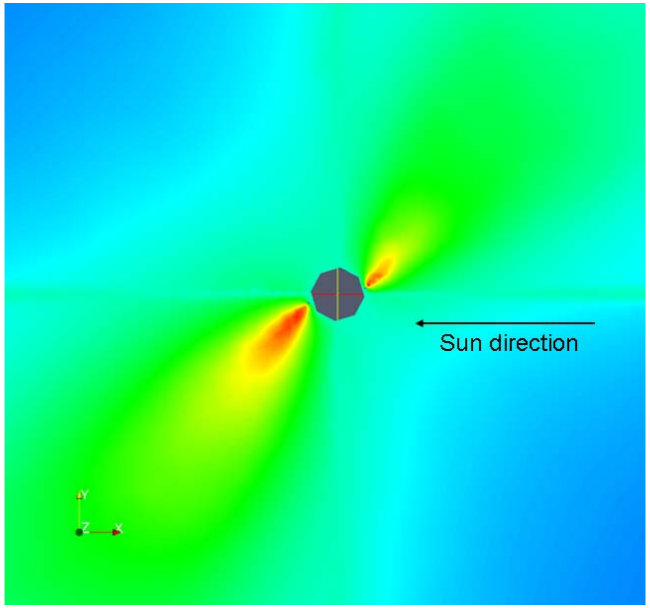
Emitter Module Details



Breadboard Emitter Module Manufacturing at AIT

- Simulation of electric potential and field during ion emitter operation in several environmental conditions
    - Performed by S. Clucas and D. Rodgers under ESTEC contract using Spacecraft Plasma Interaction Software (SPIS)





plume potentials for large Debye length (700 m)