Surface Charging Analysis of the Radiation Belt Storm Probes (RBSP) and Magnetospheric MultiScale (MMS) Spacecraft

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From Science to Solutions

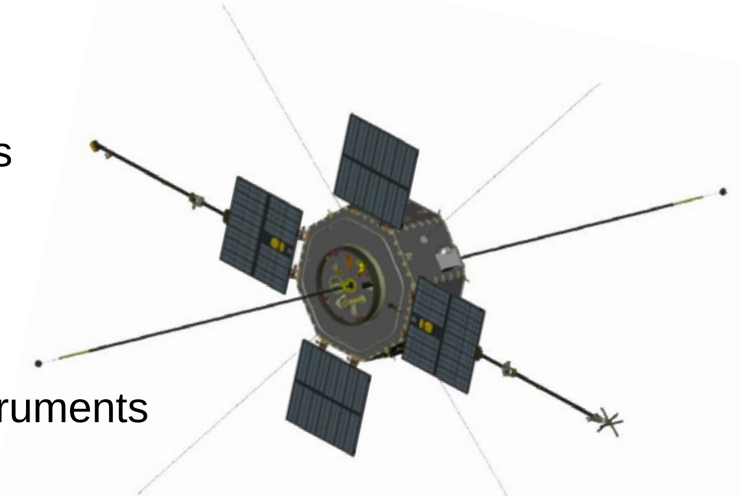
Spacecraft Surface Charging Analysis

- What surface potentials (chassis and differential) can be expected?
- How will these potentials change with sun direction and spacecraft operations?
- How will these surface potentials influence the measurements?
- Can differential potentials that are high enough to cause discharges occur?

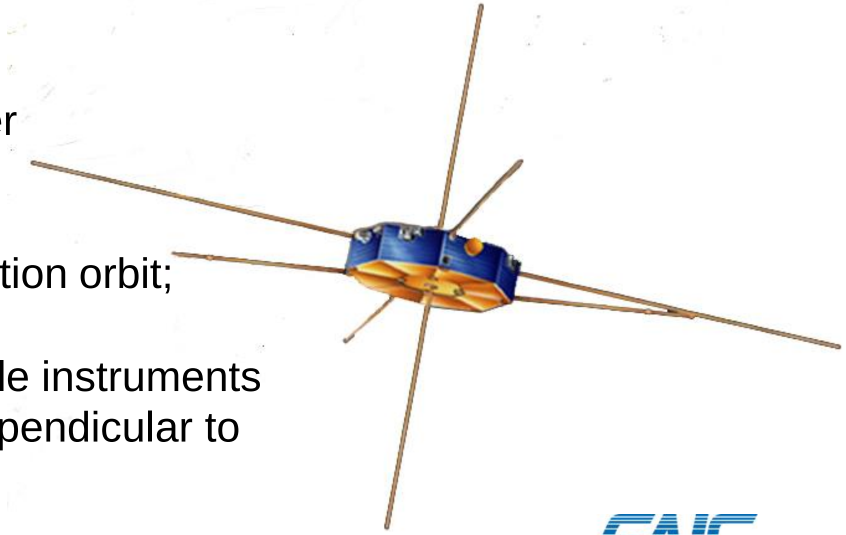
Outline of Discussion

- Missions
  - Radiation Belt Storm Probes (RBSP)
  - Magnetospheric MultiScale (MMS)
- Surface potentials in magnetosphere
  - *Nascap-2k* models
  - Geosynchronous substorm
  - High secondary yield environments
  - Low temperature environments
  - Rotation
- Electric field measurements
  - Large scale potential variations
  - Spacecraft axial asymmetry
  - Contribution of differential potentials
- Conclusions

Missions



- Radiation Belt Storm Probes (RBSP)
  - Built by Johns Hopkins University Applied Physics Laboratory for NASA’s Living with a Star program
  - Pair of satellites
  - 2012 launch, two-year mission
  - 700 x 30,600 km, 10° inclination orbit
  - Includes electric field and low energy particle instruments
  - Spin rate of 5 RPM; spin axis 20° off sun-pointing



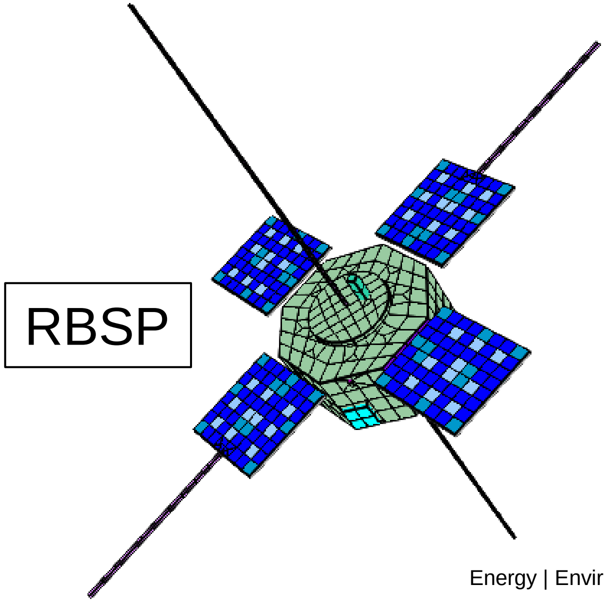
- MultiScale Magnetosphere (MMS)
  - Built by NASA/Goddard Space Flight Center
  - Four satellites in tetrahedral formation
  - 2014 launch, two-year mission
  - 1300 x 70,000 km (1.2 x 12 R_E), 28° inclination orbit; boosted to 1.2 x 25 R_E
  - Includes electric field and low energy particle instruments
  - Spin rate of 3-4 RPM; spin axis 2° from perpendicular to Earth-Sun line

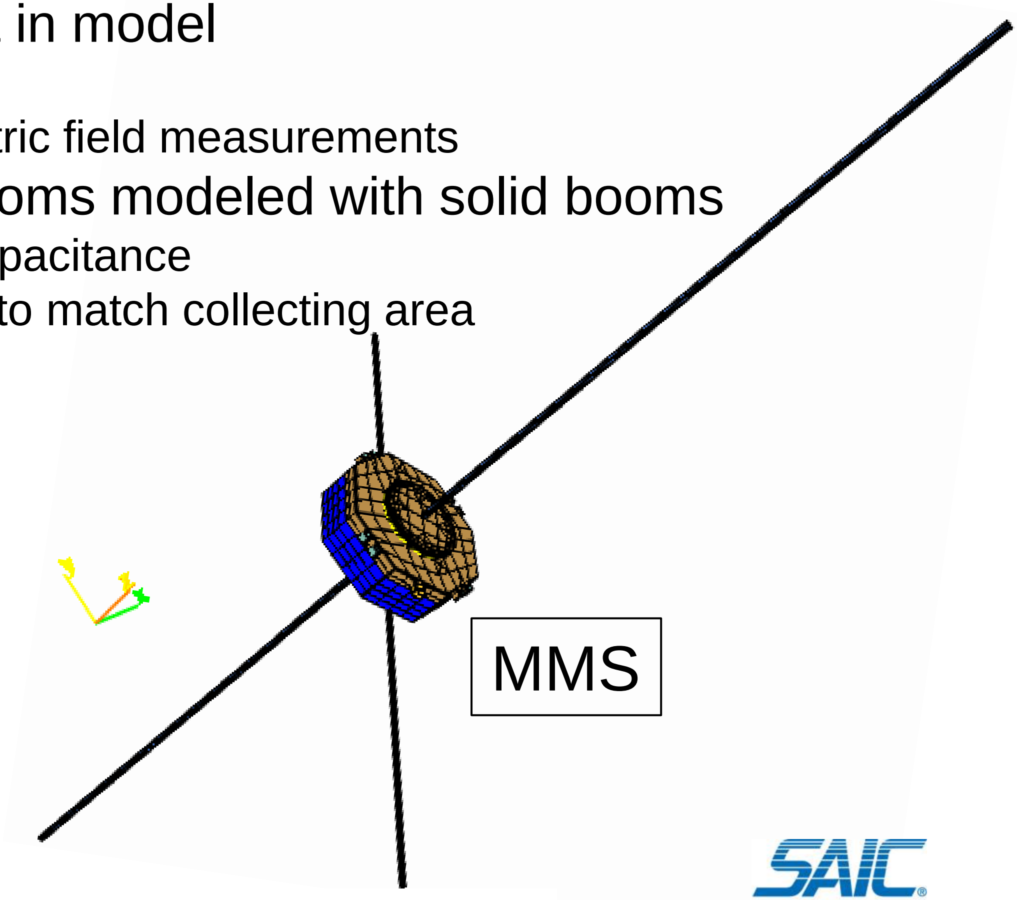
Electrostatic Cleanliness

- Environments
  - Tenuous, hot plasma (~10^6 m^{-3}, ~10^4 eV) near geosynchronous altitudes during substorms
  - Tenuous, moderate energy plasma (10^4 to 10^8 m^{-3}, 1 to 10^4 eV)
  - Dense, cold plasma (~10^{12} m^{-3}, ~0.1 eV for RBSP; ~10^{10} m^{-3}; ~1 eV for MMS) near perigee
- Surface potentials complicate measurements of electric fields and low energy particle fluxes
  - Requirement for less than 1 V differential potential=> conductivity requirements
  - Almost all surfaces conductive and grounded
  - ITO coated solar cell coverglass
  - No exposed voltages; solar cell sides and interconnects covered
  - MMS has active ion beam to keep potential < +4 V, ASPOC
- Region of scientific interest
  - RBSP: entire orbit because mapping radiation belts
  - MMS: above 9 R_E because interested in reconnection

Nascap-2k Models

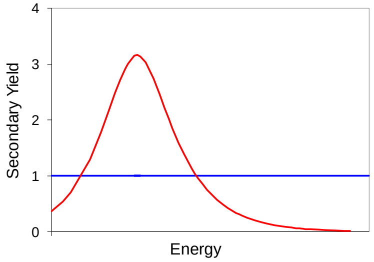
- Include insulating surfaces, particle detectors, and the axial and magnetometer booms
- Very thin spin plane booms not in model
  - Introduce numeric difficulties
  - Estimate influence on axial electric field measurements
- MMS deployable truss axial booms modeled with solid booms
  - Use 0.1 m diameter to match capacitance
  - 0.1 m boom is 0.76 transparent to match collecting area

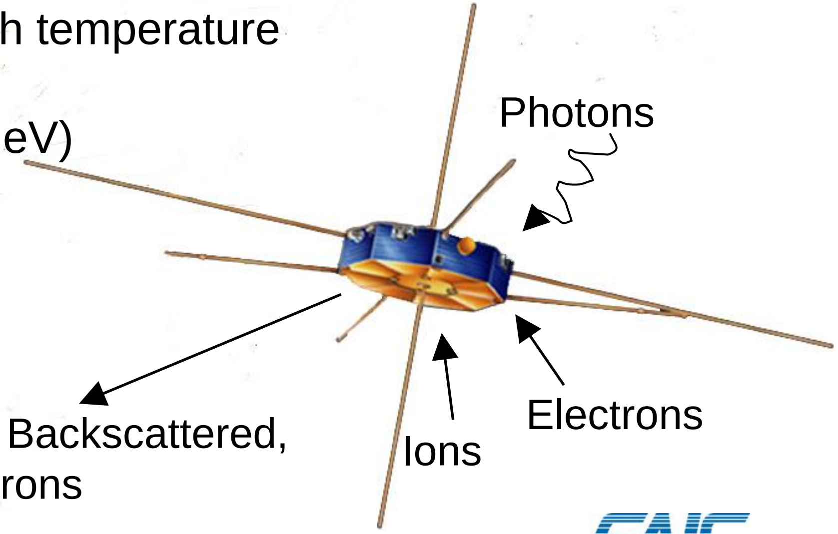




Magnetospheric Spacecraft Surface Charging

- Potential of each surface adjusts until net current is zero
- Absent barrier formation, insulators charge independently from chassis
- Sunlit surfaces positive to re-attract most ejected photoelectrons
  - See poster *Photoemission Driven Charging in Tenuous Plasma*
- For 30 eV < θ_e < 2000 eV, $-I_e + I_{sec} > 0$ for most materials, even shaded insulating surfaces at positive potentials
- Magnetospheric environments:
  - Geosynchronous substorm and other high temperature (θ_e > 2000 eV)
  - High secondary yield (30 eV < θ_e < 2000 eV) (rare for RBSP)
  - Low temperature (θ_e < 30 eV)





Photons

Secondary, Backscattered, Photo Electrons

Ions

Electrons

Geosynchronous Substorm Differential Potentials

- Significant negative chassis charging will not occur in sunlight
- Shaded insulating surfaces may develop kilovolt differential potentials and possibly arc discharges
- Calculations were done for 15 minutes in very severe “NASA Worst Case” environment in sunlight and in eclipse

	Thickness (mm)	Sun Angle	Sunlit Potential (V)	Eclipse Potential (V)
MMS Chassis			+3.9	-19,000
Cover	0.127	5°, 85°, shaded	+3.2 to -2900	-19,000
Connector	1.0	85° and shaded	-8000 to -12,000	-19,000
Foam	1.0	shaded	-12,000	-19,000
RBSP Chassis			+3.5	-22,000
Grout	0.635	20°	+0.4	-23,000
Sun Sensor	0.127	20°	+0.5	-22,000
Shaded Insulator	0.127	shaded	-4500	-22,000

- Thick insulators and electrically isolated components of concern
- EMI shielding should be verified for discharges that may occur at the thickest insulators

High Secondary Yield Environments

($30\text{ eV} < \theta_e < 2000\text{ eV}$; MMS Only)

- MMS most often in environments with $-I_e + I_{sec} > 0$, so even shaded surfaces at positive potentials
- Without ASPOC ion beam, chassis potentials ~+40 V in very low density plasma of magnetotail
- Shaded insulators may differentially charge negative to remain near plasma ground
- Insulators may have differential potentials on the order of +10 V and -40 V without ASPOC and +50 V and -2 V with ASPOC
- Results consistent with experience

	Env 1	**Env 2**	**Env 3**	**Env 4**
Temperature (eV)	350	2000	300	1000
Thermal Current ($\mu A\ m^{-2}$)	80	6.0	0.93	0.008
Sunlit Chassis with ASPOC off (V)	2.3	3.4	7.6	42
Eclipse Chassis with ASPOC off (V)	N/A	2.6	N/A	3
Insulator with Normally Incident Sun (V)	3.3	3.2	14.8	56
Shaded Insulator (V)	3.1	1.7	3.1	2.5

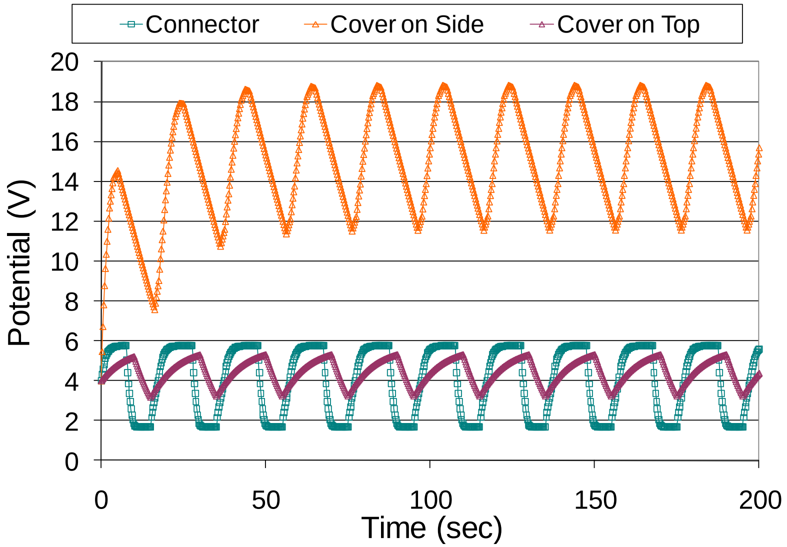
Low Energy Environments

- Below about 30 eV (depending on the material) few secondary electrons are ejected
- Shaded surfaces charge negative to repel plasma electrons
- Surfaces in wake of plasma flow have enhanced negative charging

	MMS				**RBSP**
	Plasma Plume 1	**Plasma Plume 2**	**Low Temperature Solar Wind**	**18 eV**	**Geosynchronous, Local Noon**
Temperature (eV)	0.6	1	15	18	5
Thermal Current (μA m^{-2})	0.83	0.134	1.04	0.114	0.899
Sunlit Chassis with ASPOC off (V)	2.2	5.9	5	13	4.5
Eclipse Chassis with ASPOC off (V)	N/A	N/A	N/A	-21	N/A
Directly Sunlit Insulator (V)	1.3	8	9.8	22	3
Shaded Insulator (V)	-1.5	-2.5	-50	-27	-11
Insulator on Side (V)	-1.5 to 1.3	-1.5 to 6.7	-11 to 7	3.5 to 10.5	N/A

Effect of Rotation (MMS)

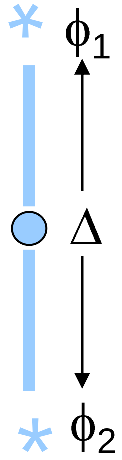
- When rotation is included, surface potentials of thinner surfaces may not reach equilibrium values
- Electrically isolated and thick layers (Connector) reach equilibrium potential quickly
- Thin layers (Cover) reach equilibrium potential slowly
- Chassis held at 4 V by ASPOC



Electric Field from Surface Potentials

- Measured field is potential difference between two symmetrically opposite points, $E = \phi_2 - \phi_1 / \Delta$
- Dipolar potential of value ±0.5 V

	RBSP	MMS
Radius of equivalent sphere (m)	0.96	1.4
Distance to electric field sensor (m)	6	15
Potential at axial electric field sensor (mV)	±13	±4.1
Spacecraft electric field (mV/m)	2.2	0.26
Target axial field accuracy (mV/m)	4	1



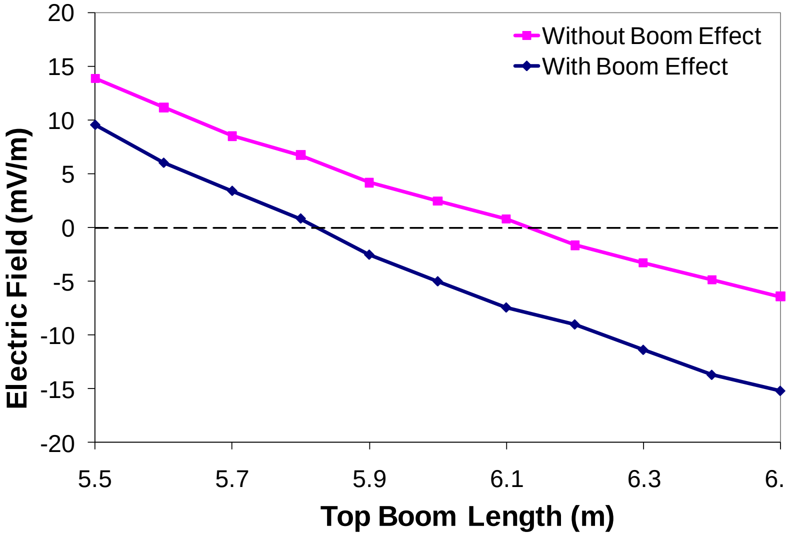
- A dipolar field can result from
  - Asymmetric charge on the spacecraft
    - Probably impossible to correct
  - Geometric asymmetry of a uniformly charged spacecraft
- Analytic result for 10-cm radius patch (300 cm^2) differentially charged to 50 V (ignores spacecraft capacitance)

Potential at axial electric field sensor (mV)	25	3.3
Spacecraft electric field (mV/m)	2.1	0.11

Asymmetric Spacecraft Creates Dipolar Field

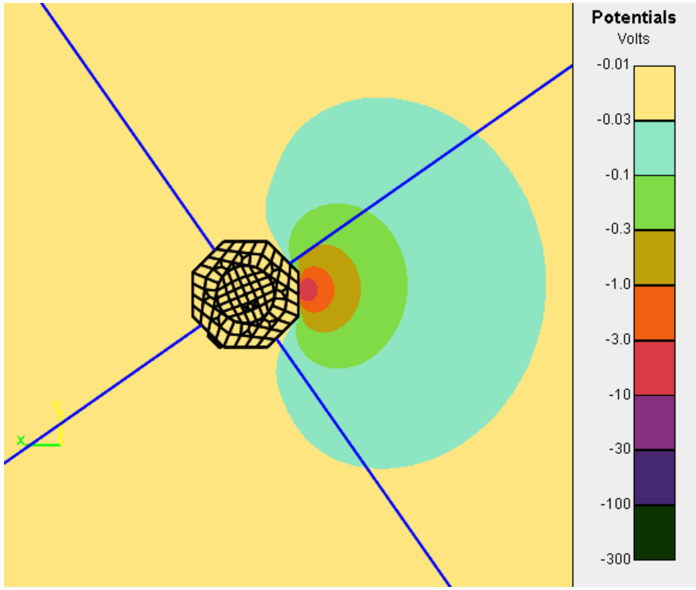
- Source of axial asymmetry
  - RBSP: Solar array panels
  - MMS: Spin plane booms 0.27 m above body center and magnetometer booms below center
- Correction
  - RBSP: Axial booms lengths to be adjusted on orbit
  - MMS: Bottom axial boom inset about 10 cm
- Calculation
  - Spin plane booms approximated by spheres with same potential and electric field at detector
  - Similar calculation for MMS shows ~25 cm inset needed; remaining field to be corrected for in data analysis
  - Assumes no debye shielding

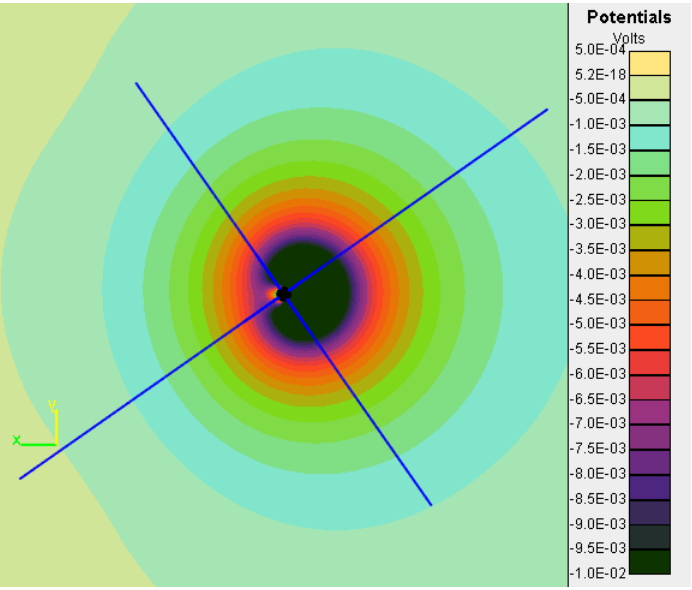
RBSP Axial Electric Field as Function of Top Detector Position for +4 V chassis



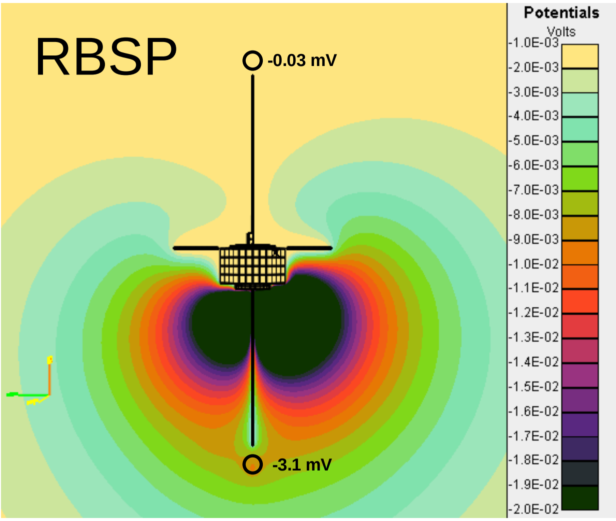
Insulators Have No Influence on Spin Plane Electric Field Measurements

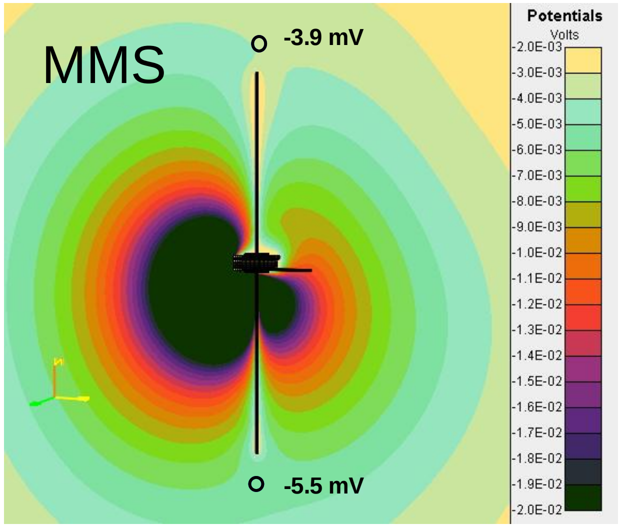
- Solve Laplace’s equation for RBSP
  - 26.7 cm^2 shaded insulator at -1 kV; chassis at +0 V
  - Monopole boundary conditions on grid boundary
- Resulting difference at ends of spin plane booms
  - ~0.45 mV/80 m << 0.3 mV/m requirement
  - Results similar for MMS





Axial Booms Reduce Spacecraft-generated Field





- Analytic result for 300 cm^2 at 50 V

	RBSP	**MMS**
Spacecraft electric field (mV/m)	2.1	0.11
Target field accuracy (mV/m)	4	1

- Laplace’s equation with spacecraft geometry gives potentials at axial electric field detectors
  - Calculation includes capacitance of all surfaces
- Spacecraft surfaces
  - Chassis at 0 V
  - RBSP: 0.06 m^2 at –50 V
  - MMS: 0.11 m^2 at –50 V
- Spacecraft-generated field
  - RBSP: 0.3 mV/m
  - MMS: 0.05 mV/m
- With debye screening, potentials will be smaller

Conclusions

- Computed RBSP and MMS surface potentials and consequences
- RBSP and MMS have a high degree of electrostatic cleanliness
- Surface potentials expected to have acceptable impact on measurements
- Surface potentials controlled by
  - Tenuous plasma => sunlit surfaces float positive
  - Dense plasma and shaded surfaces => negative potentials
  - $-J_e + J_{sec} > 0$ => shaded surfaces +1 to +2 V
  - Low current => surface potentials never reach equilibrium
- Spacecraft axial asymmetry creates measurable axial field
  - Reduced by different length booms
- Differentially charged insulators create electric field
  - Spacecraft capacitance reduces field
  - 0.1 m^2 => E << requirement