Nascap-2k Spacecraft Charging Code Overview

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Outline

- *Nascap-2k*
  - What is it?
  - Core capabilities
  - Recent progress
- *Object Toolkit*
- *Nascap-2k* user interface
- Examples:
  - Geosynchronous charging
  - LEO current collection
  - Electrostatic thruster plumes
  - Antenna-induced currents
- Summary

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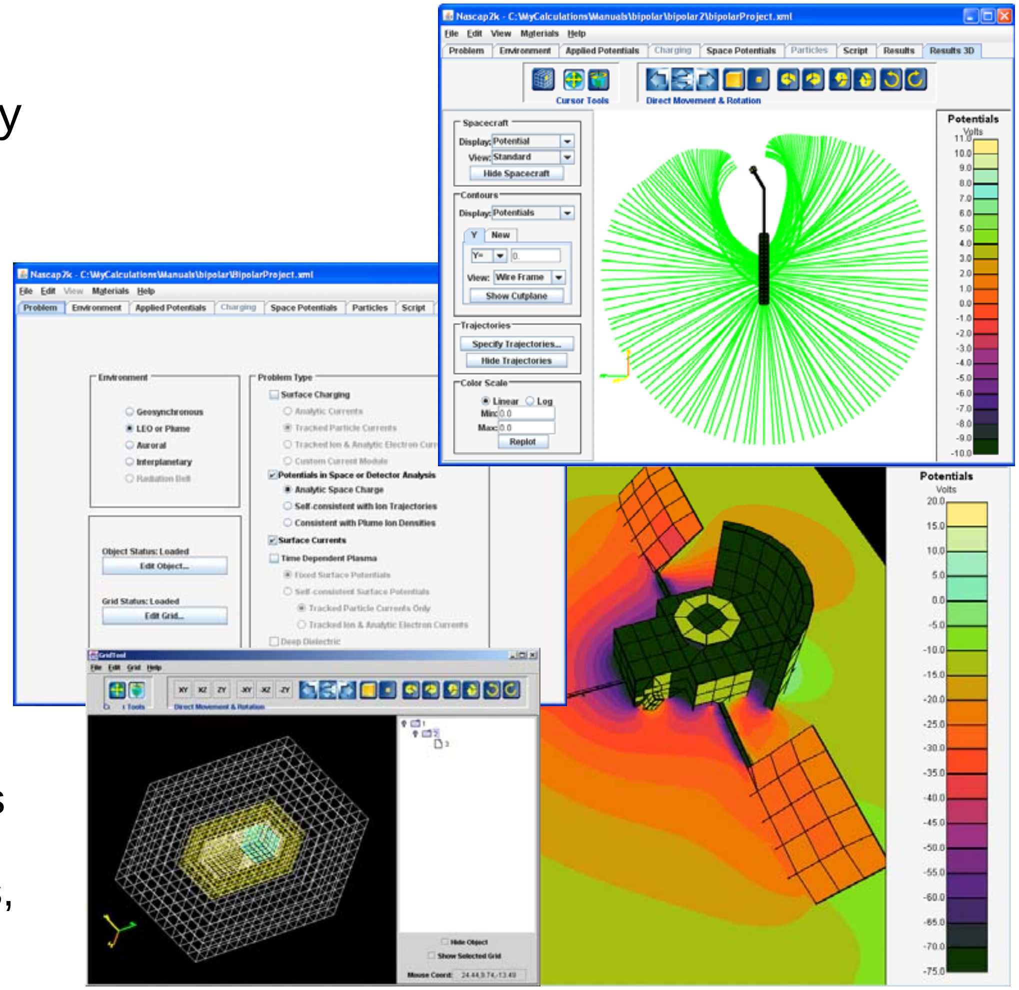
What Is *Nascap-2k*?

- *Nascap-2k* is a fully three-dimensional computer code to calculate the interaction of a spacecraft with its plasma environment
- Interactions include:
  - Surface potentials
    - Charged particle spectra
    - Secondary electron emission
    - Bulk and surface conductivity
  - Current collection
    - Applied potentials
  - Perturbation of near-field environment
    - Plasma sheaths
  - Thruster plumes
    - Charge exchange ion flow
- Calculations are analytic where possible, PIC (particle-in-cell) where required
- Code features
  - Object and grid definition
  - Simplified user interface for problem definition and execution
  - Graphical display of results
- Air Force Research Laboratory and NASA sponsorship

Nascap-2k Core Capabilities

- Define spacecraft surface geometry
- Grid surrounding space
- Calculate environmentally induced time-dependent surface potentials
- Calculate external potentials:
  - Analytic space charge (5 models)
  - Macroparticle space charge (4 models)
- Generate and track macroparticles
  - Uniform with boundary injection
  - Sheath generation
  - Charge exchange
- Post-processing:
  - Time-dependent surface potentials and currents
  - Time-dependent volume potentials, currents, and densities



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Progress Since 2005

- Included in current release (Version 3.2)
  - Thruster plume interactions
    - M. J. Mandell *et al*., “Modeling the NEXT Multithruster Array Test with *Nascap-2k*,” *IEEE Trans. Plasma Science 36*, 2309, October 2008
  - Macroparticle splitting
    - Accounts for thermal effects
  - Orbit averaged PIC
  - Multiple cutplane display
  - ScriptRunner for calculations outside user interface (for long-running PIC)
- In preparation for next release (Version 4.1)
  - New flexible database
  - Environment: Kappa distribution function implemented; flowing Maxwellian and tabular under development
  - Surface and volume currents
    - See Poster Paper “Pseudopotential Algorithms for Simulation of VLF Plasma Antenna Current Flow”
  - Release expected early 2011

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New *Nascap-2k* Database

- More capabilities
  - No limit on grid size; no limit on number of particles
  - No limit on number of stored quantities. This allows for better postprocessing, more complex plasma models, and more timesteps
  - More robust
- Flexible
  - Accommodate future *Nascap-2k* growth
  - Available for other Air Force programs
- N2kDB Tool provides for direct access to the database
  - Console version
  - Java® interface and C++ dynamically linked library version
    - Can be used to write to database
- N2kDB
  - C++ dynamically linked library
  - Interfaces to Fortran, C++, and Java
- Files
  - Random access with ASCII and/or integer keys
  - Separate files for general information, special elements, pages of particles, and time-dependent information
  - Specified data item names with up to 16 characters and/or an integer

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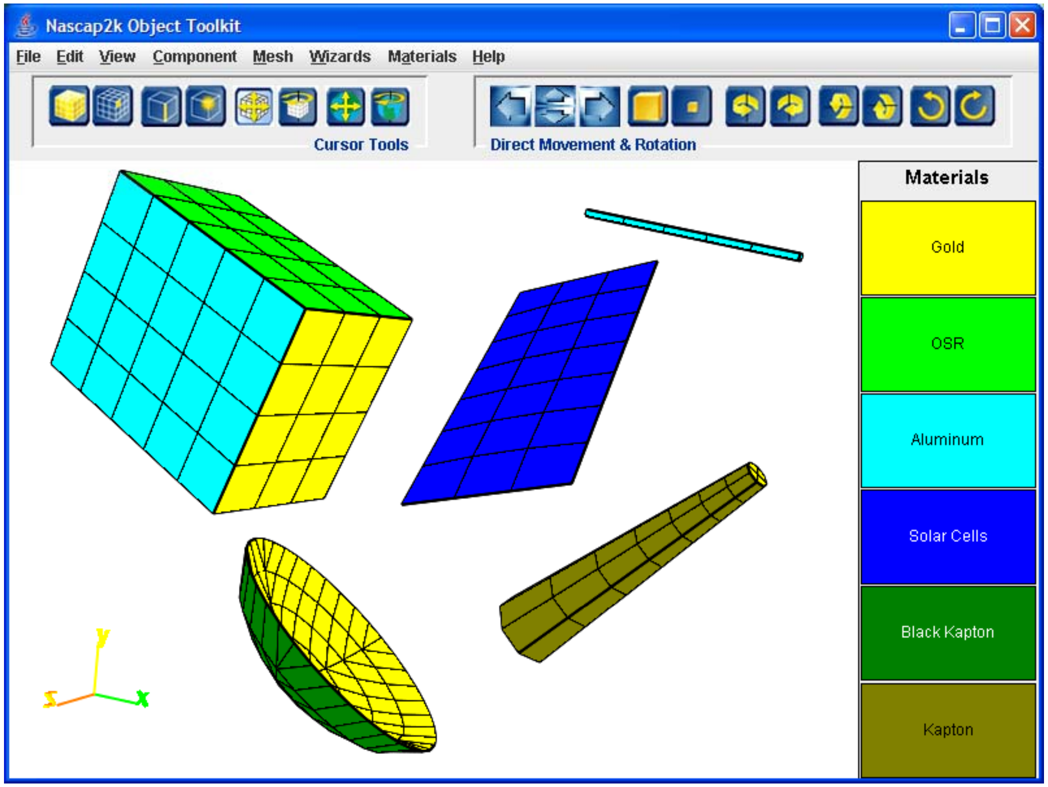
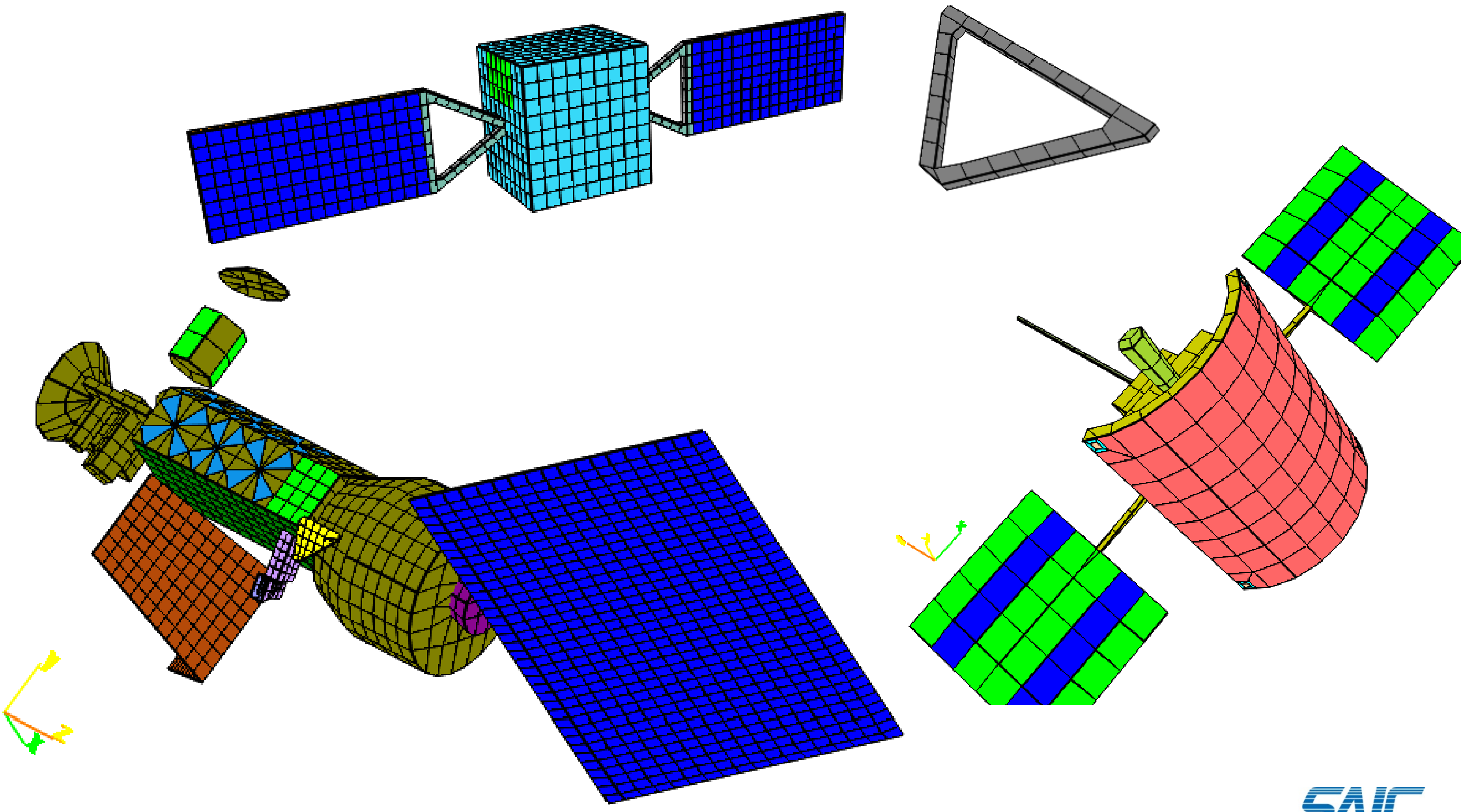
Object Toolkit

- Build spacecraft surface models
- Intrinsic building blocks
- Import from finite-element preprocessors
- Surface attributes
  - Material name
    - Conductivity
    - Secondary electron emission
  - Conductor number
- Customizable to other applications via an external file



Object Toolkit Examples



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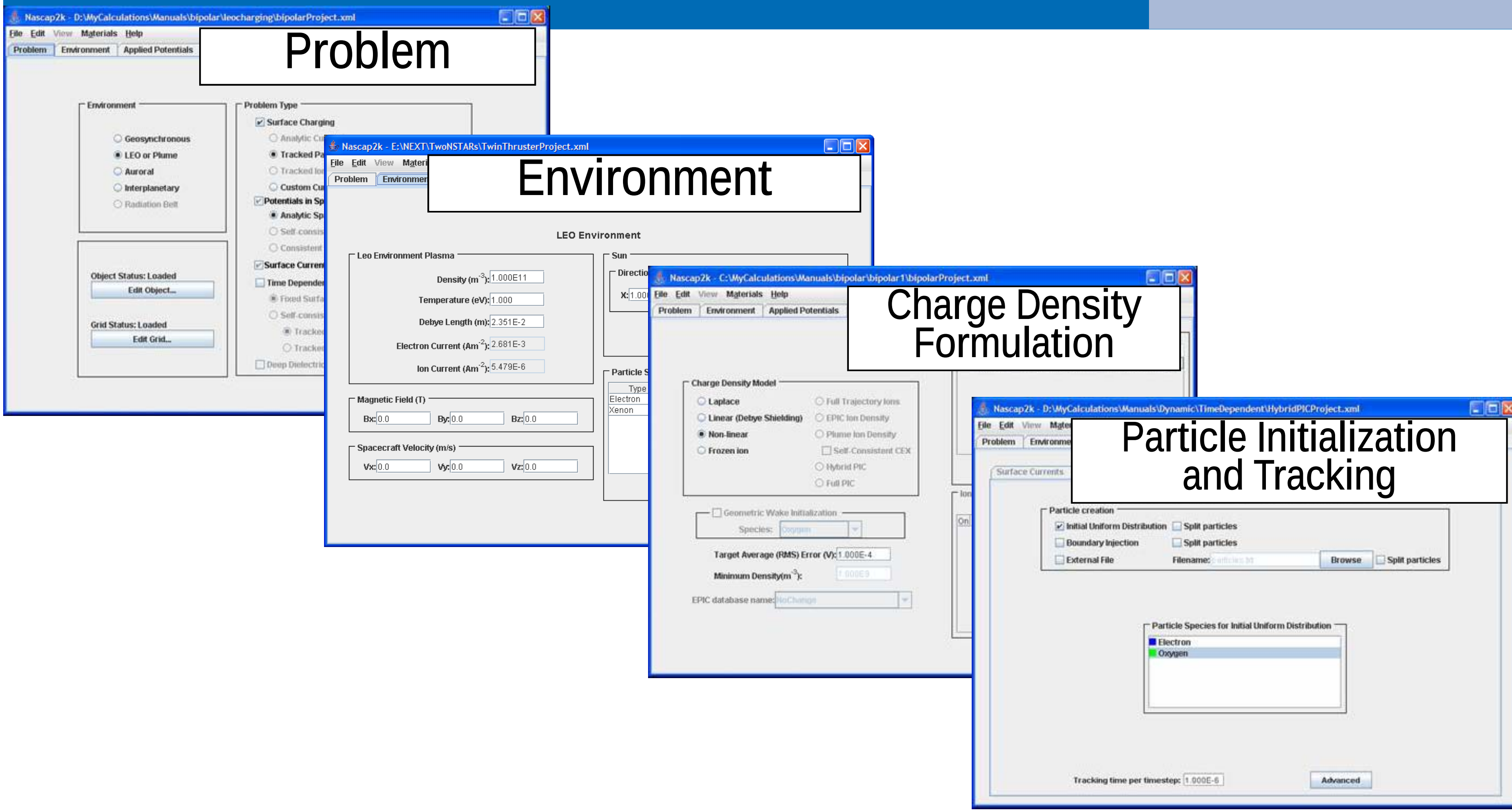
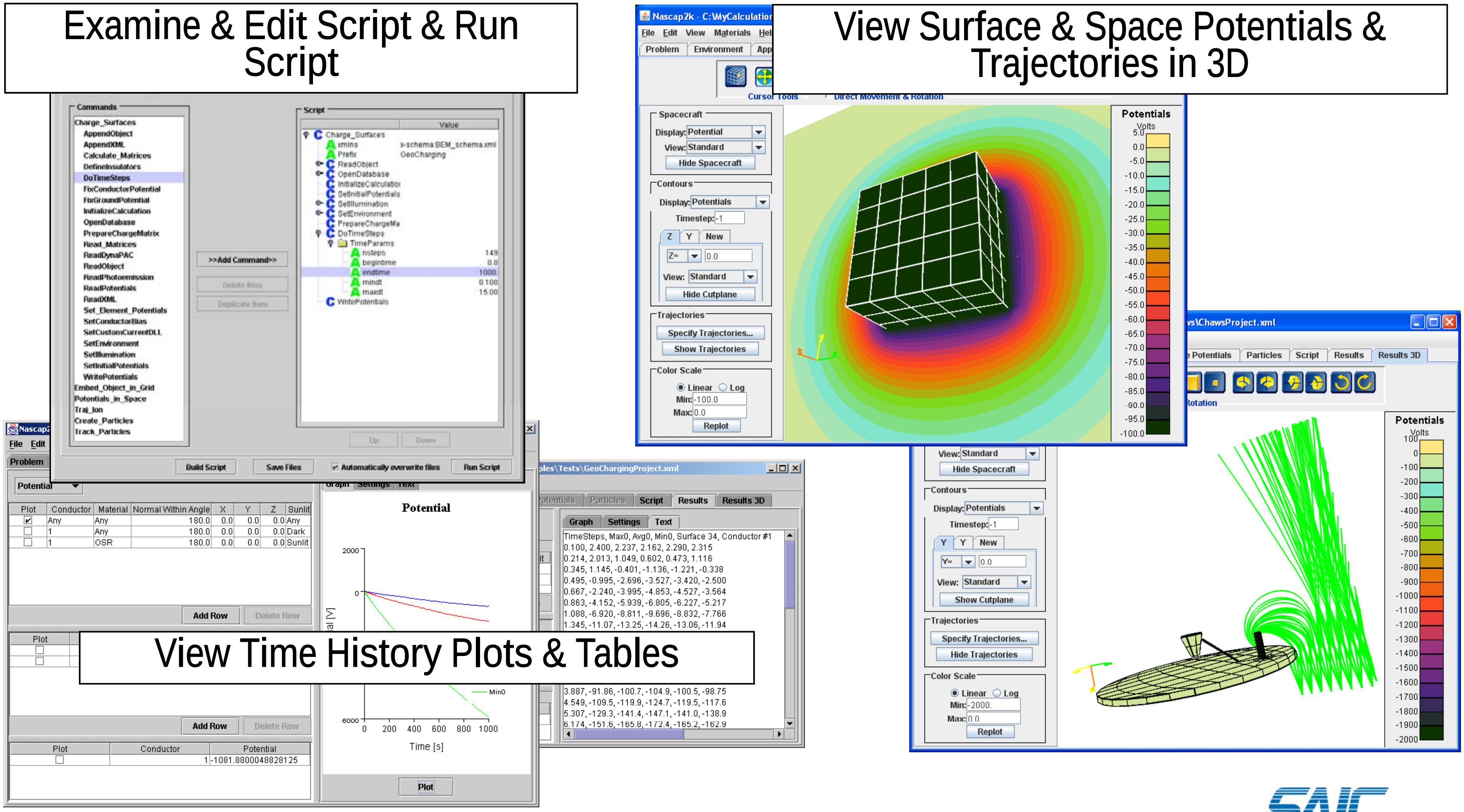
Nascap-2k GUI
Input tabs



Nascap-2k Results Tabs



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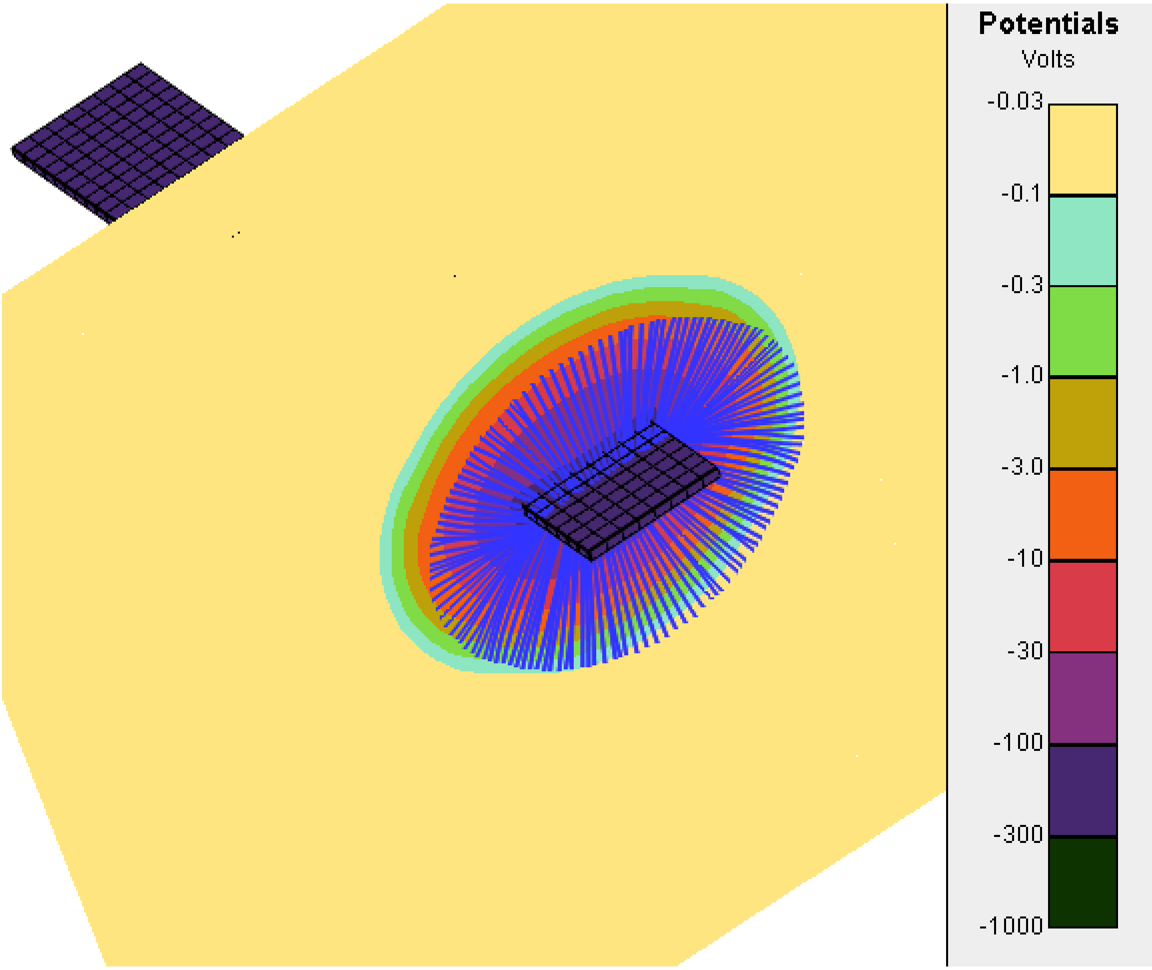
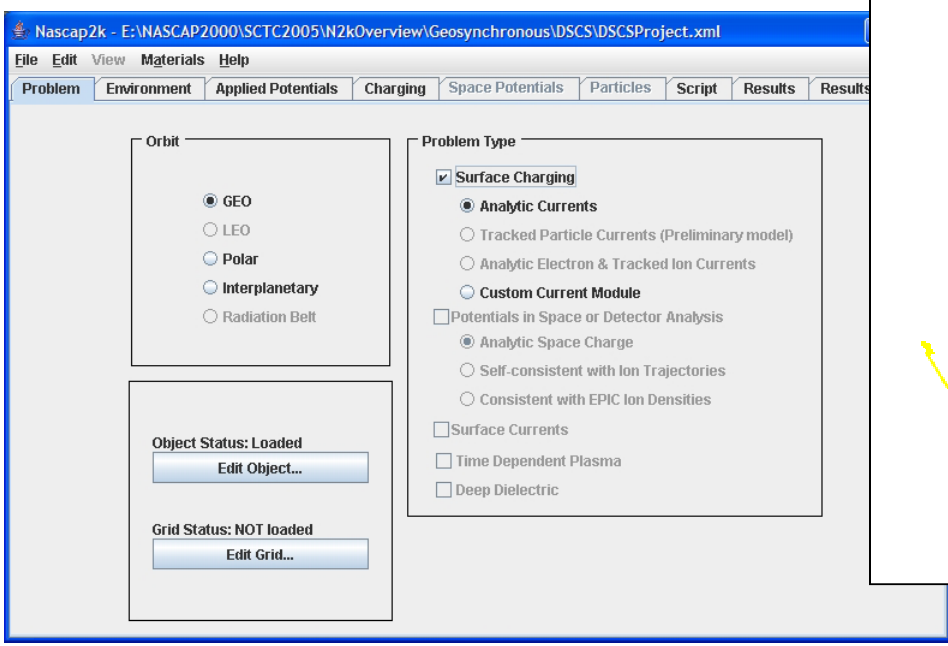
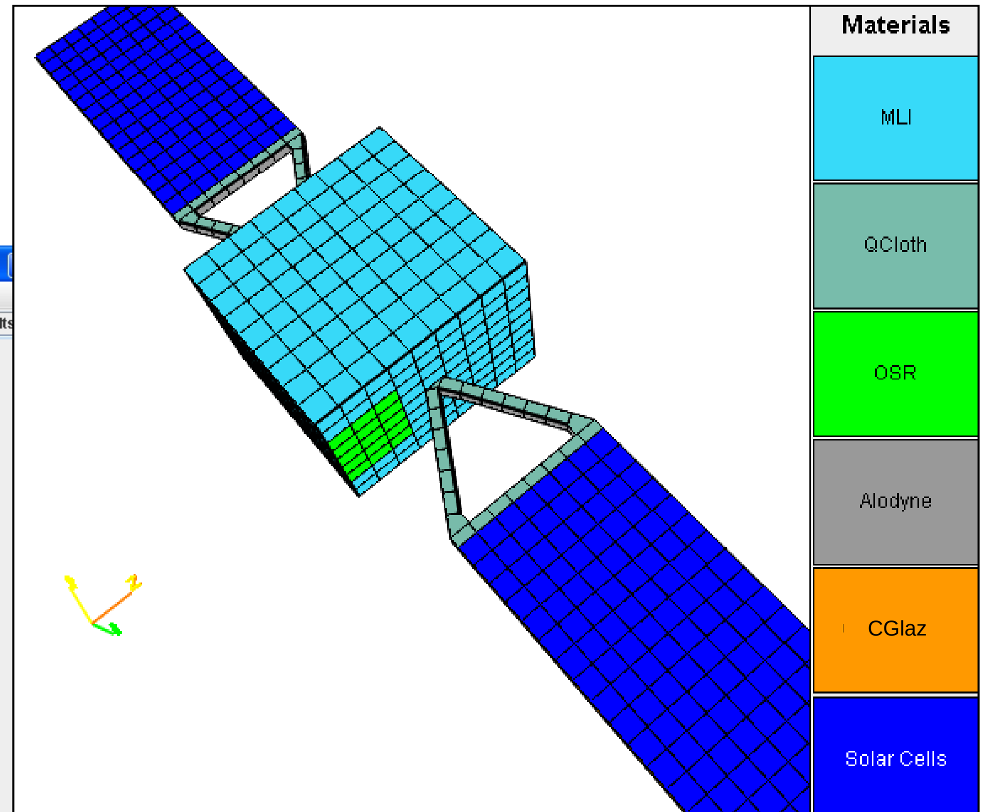
3-D Results Display
Surface Potentials, Space Potentials, and Ion Trajectories



Geosynchronous Orbit Charging (I)
Geometric Model and Problem Specification

- Spacecraft covered with insulating material
- High secondary emission on OSRs
- No grid needed because BEM (Boundary Element Method) provides electric fields





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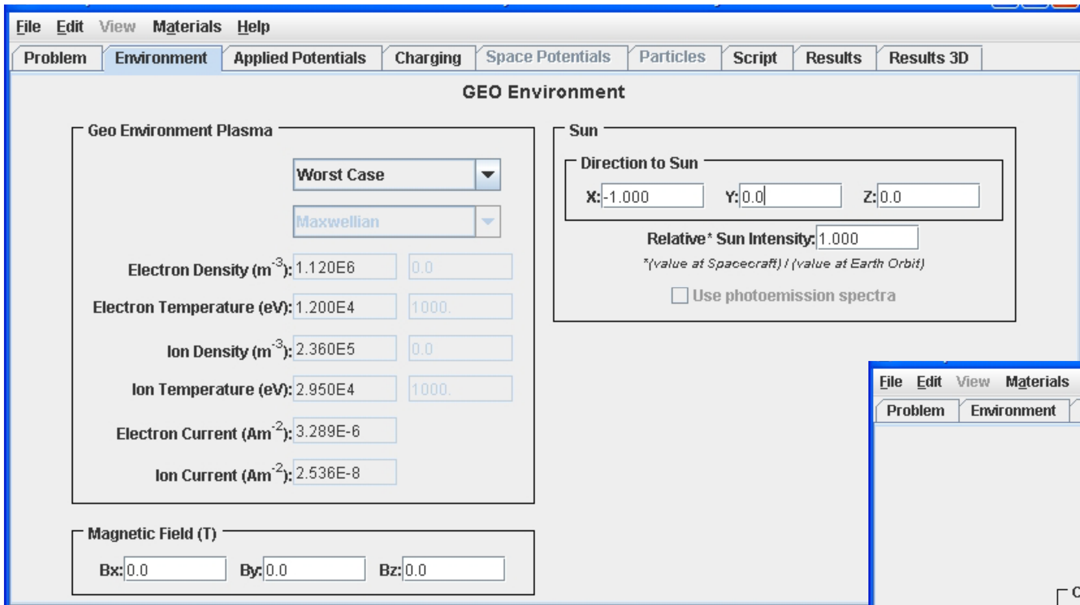
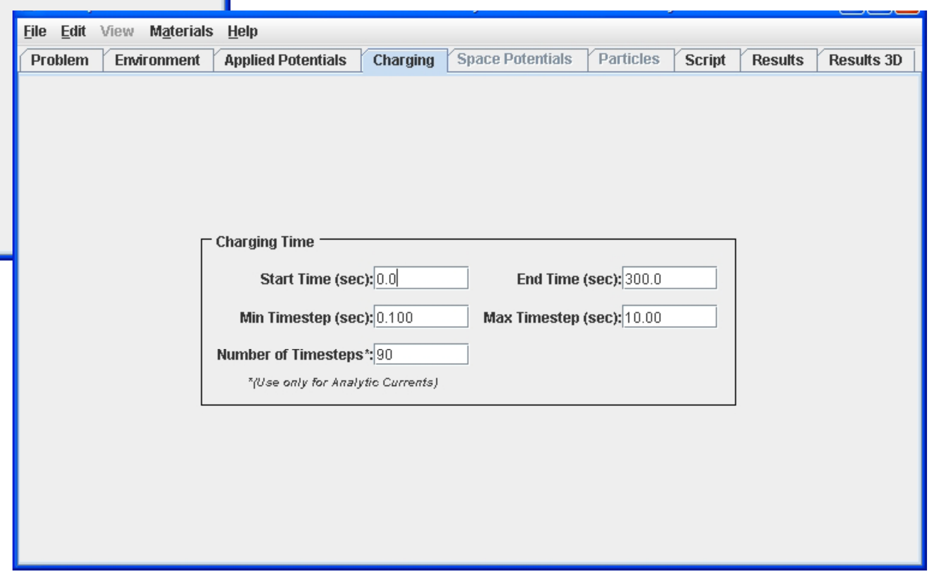
Geosynchronous Orbit Charging (II)

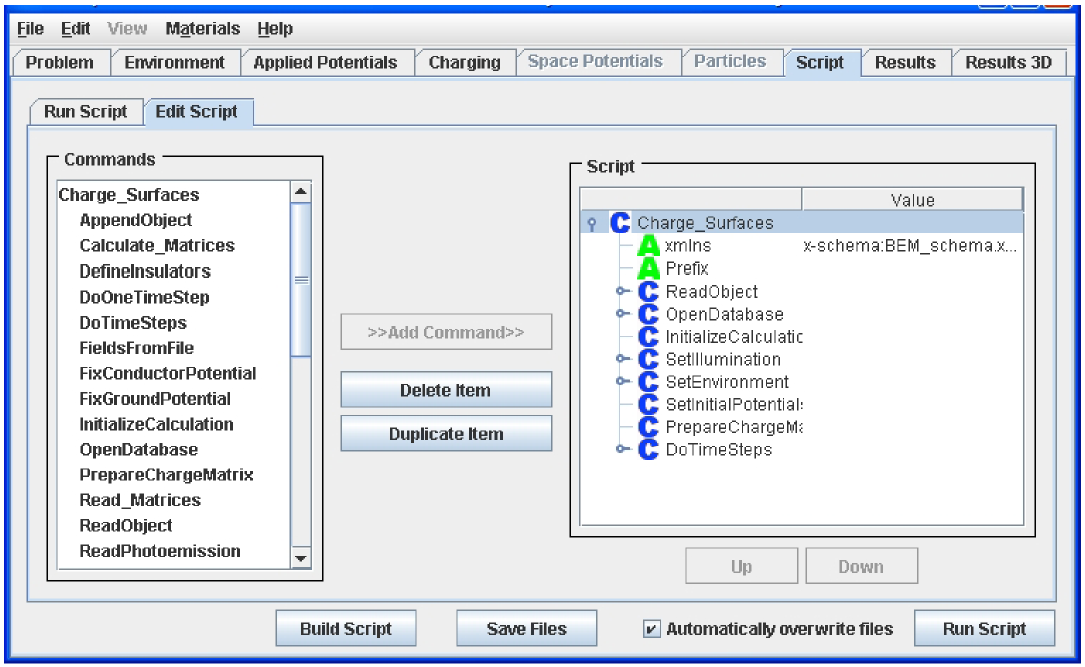
Environment and Timestepping Specifications

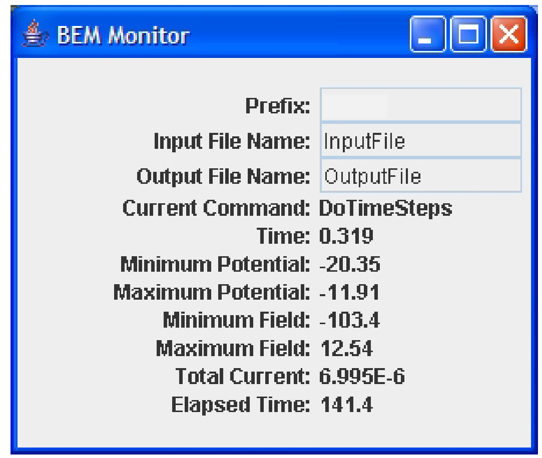




- Environment tab sets geosynchronous environment distribution function–here a Maxwellian
- Charging tab sets timestep parameters

Geosynchronous Orbit Charging (III)





- Script (automatically generated) specifies calculation steps
  - Script can be edited internally or externally
- Monitors progress of calculation
- Results in 30 minutes

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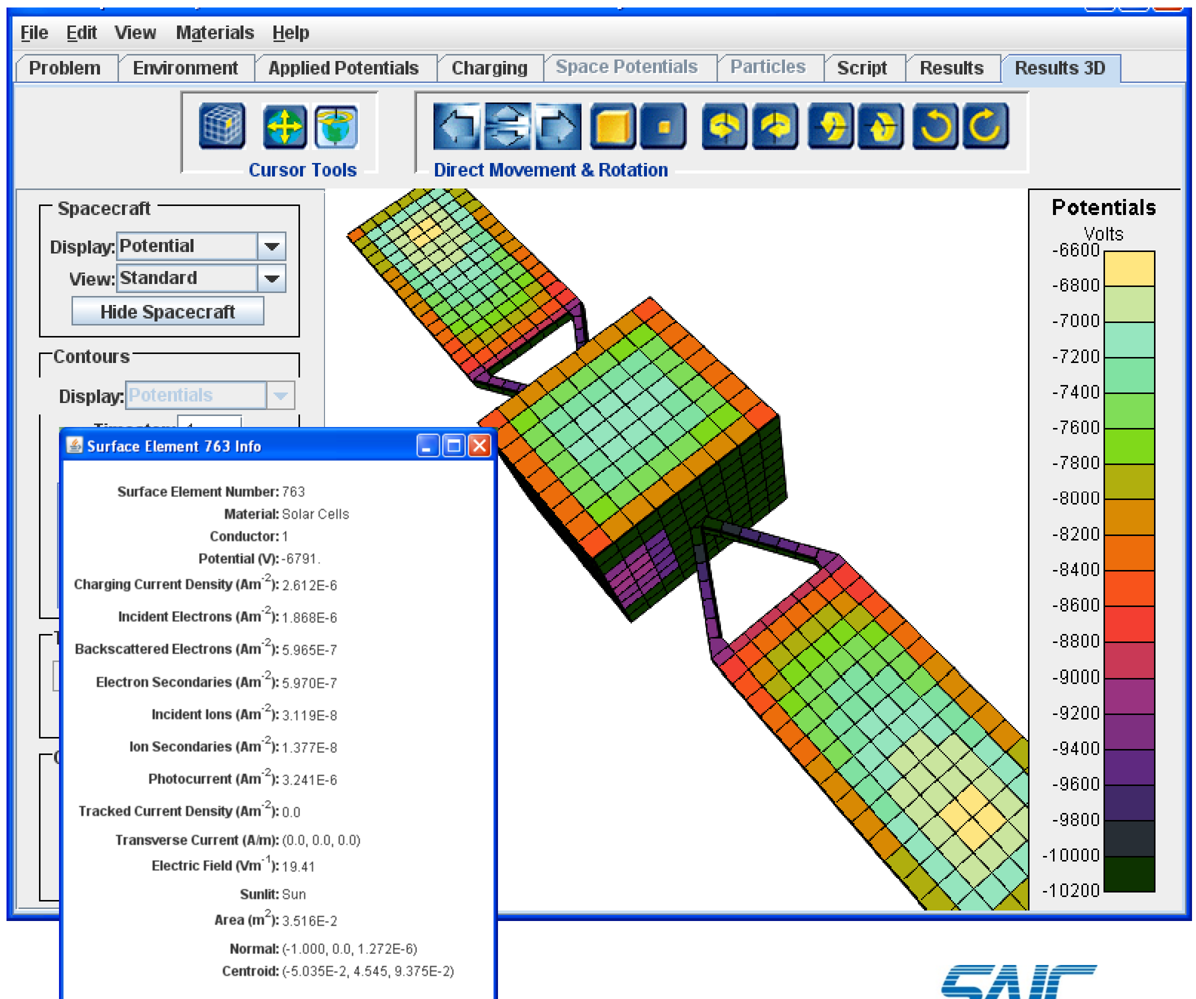
Geosynchronous Orbit Charging (IV)

Results3D Tab Display

- Positive differential charging:
  - Outboard region of solar panel
  - Center of sunward panel
  - OSR radiator panels
- Detailed information available for selected surface element
- With grid, could superpose potential contours and particle trajectories
- Results tab provides time history of surface currents and potentials



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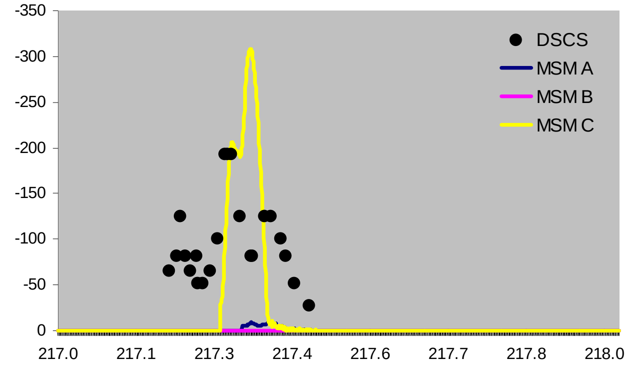
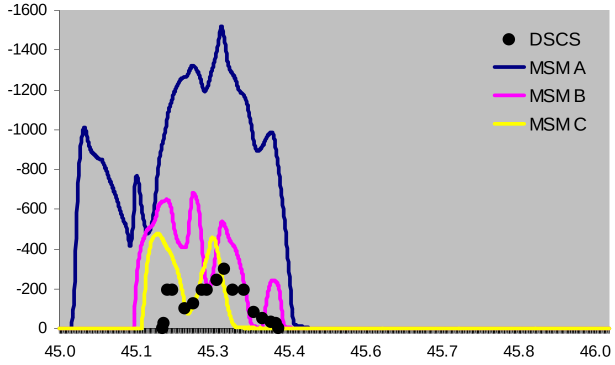
Nascap-2k Adaptable to Real-time Calculations

- *Nascap-2k* charging algorithms fast
- Algorithms used in prototype of *Nascap-2k RT*
- *Nascap-2k RT* will compute surface potentials in MSM-calculated charged particle environments in operational charging forecast system
- Figures compare measured potentials with those computed by *Nascap-2k RT* using MSM environments
  (R. Hilmer, Fall Meeting of the American Geophysical Union, 2005)

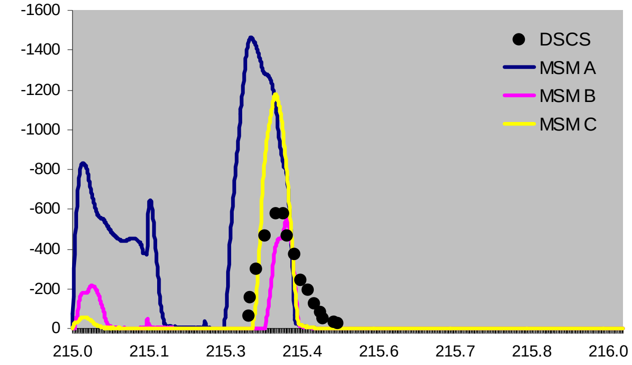
LOW CHARGING (~0.2 keV peak)



MEDIUM CHARGING (~0.3 keV peak)



HIGH CHARGING (~0.6 keV peak)



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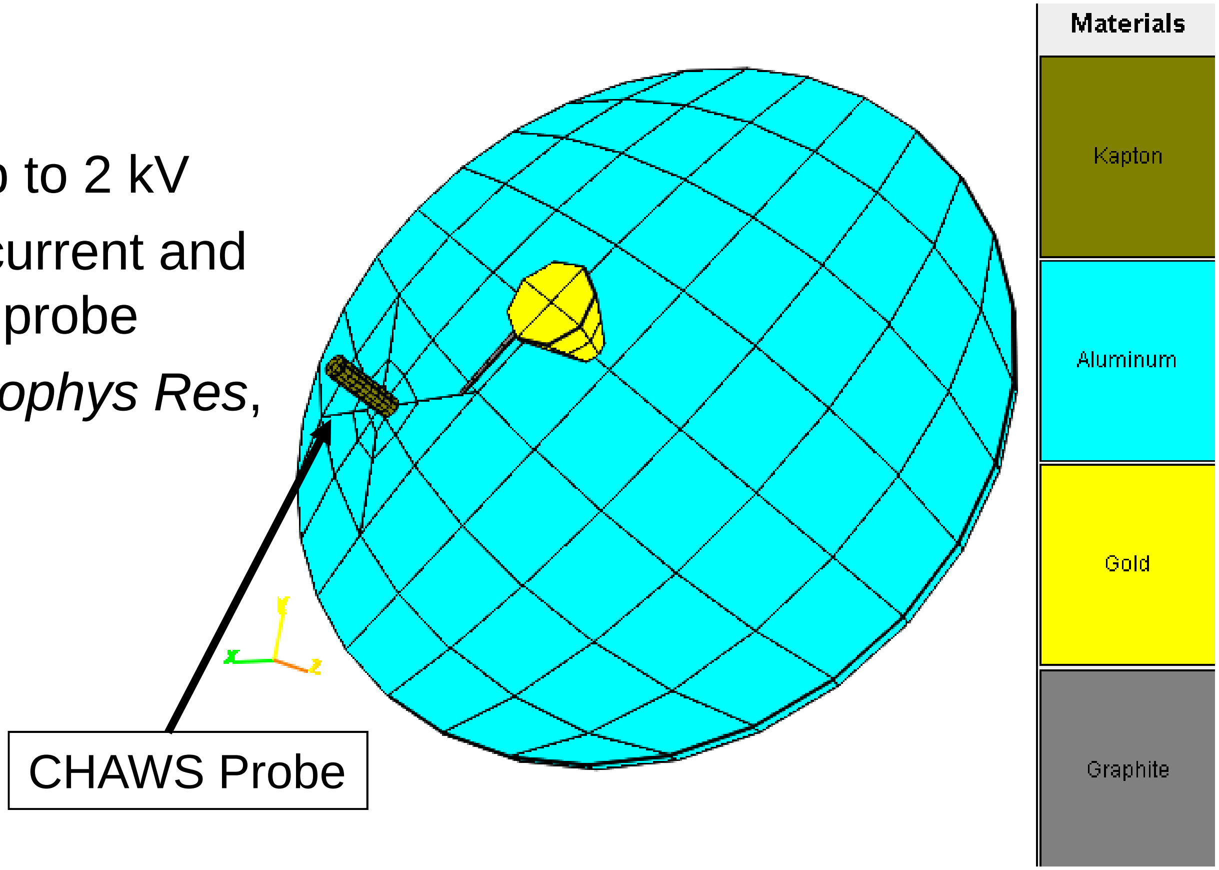
LEO Current Collection (I)
Charging Hazards and Wake Studies Experiment (CHAWS)

- Flown twice on Wake Shield Facility (WSF)
  - STS-60 (Feb. 1994)
  - STS-69 (Sept. 1995)
- Negative probe bias up to 2 kV
- Instrumented for total current and current distribution on probe
- V.A. Davis, et al., *J Geophys Res*,
- p. 12445, 1999



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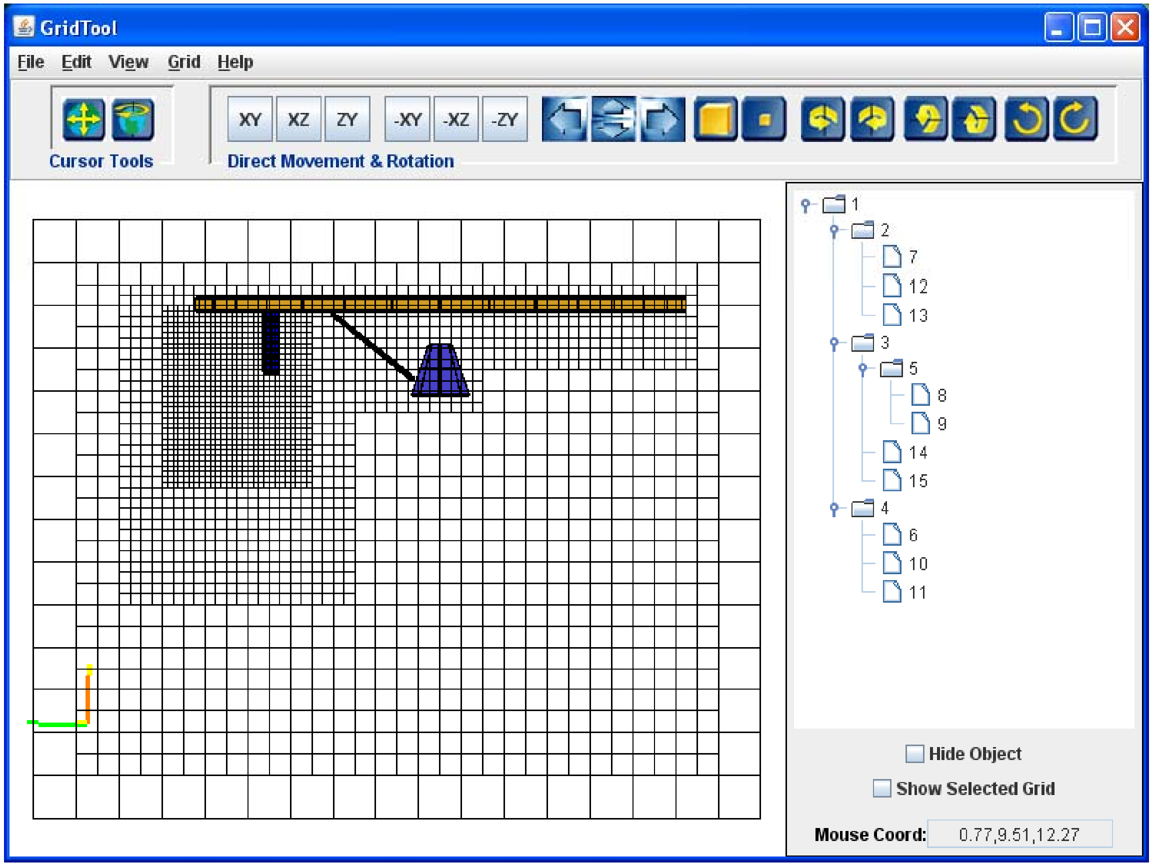
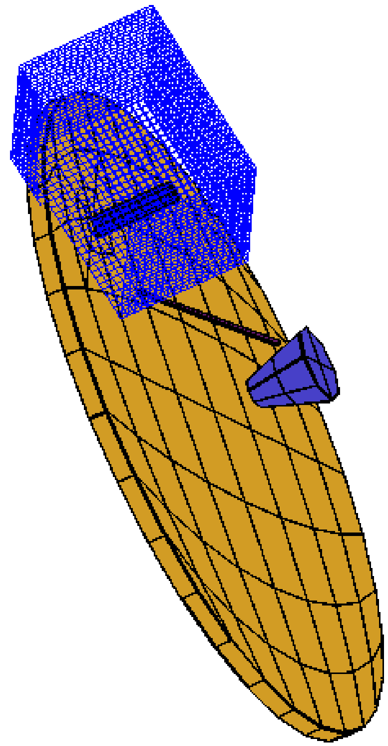
LEO Current Collection (II)
Spatial Gridding with *GridTool*



Fine resolution around probe and near edge of disk



Multiply nested cubic grids with “special” elements containing object for computational speed

Acronyms defined on last slide

LEO Current Collection (III)

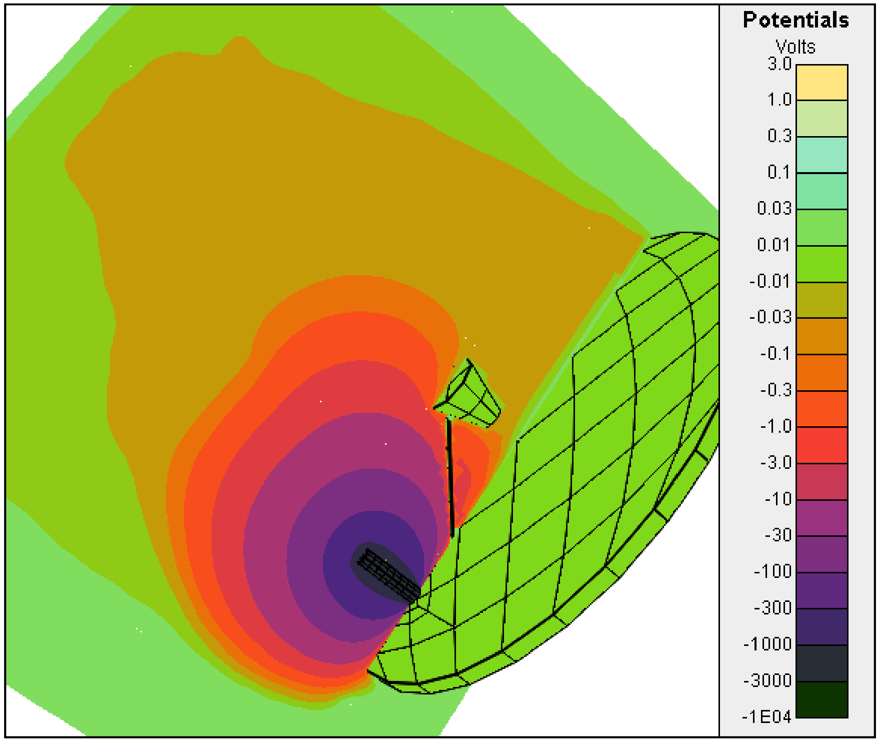
Steady-state Potential Solution

- CHAWS probe at -2 kV
- PIC ions and fluid electrons:

$$\frac{\rho}{\varepsilon_0} = \frac{\rho_{ion}}{\varepsilon_0}\left(1 - \exp\left(\left(\phi - \phi_b\right)/\theta\right)\right)$$

$$\phi_b = \theta \ln\left(\frac{\rho_{ion}}{en}\right)$$

- Charge stabilization permits mesh >> λ_{Debye}
- High voltage in wake requires tracking.
- Strictly continuous electric fields and third order particle tracking for efficiency



- Potential penetrates substantially into ram flow
- Ions near WSF edge accelerated in ram direction before attracted to probe
- O^+ ions, H^+ ions, rear surface of WSF, and WSF experiment all serve to shield the probe potential, limiting the range of high potentials in the downstream wake

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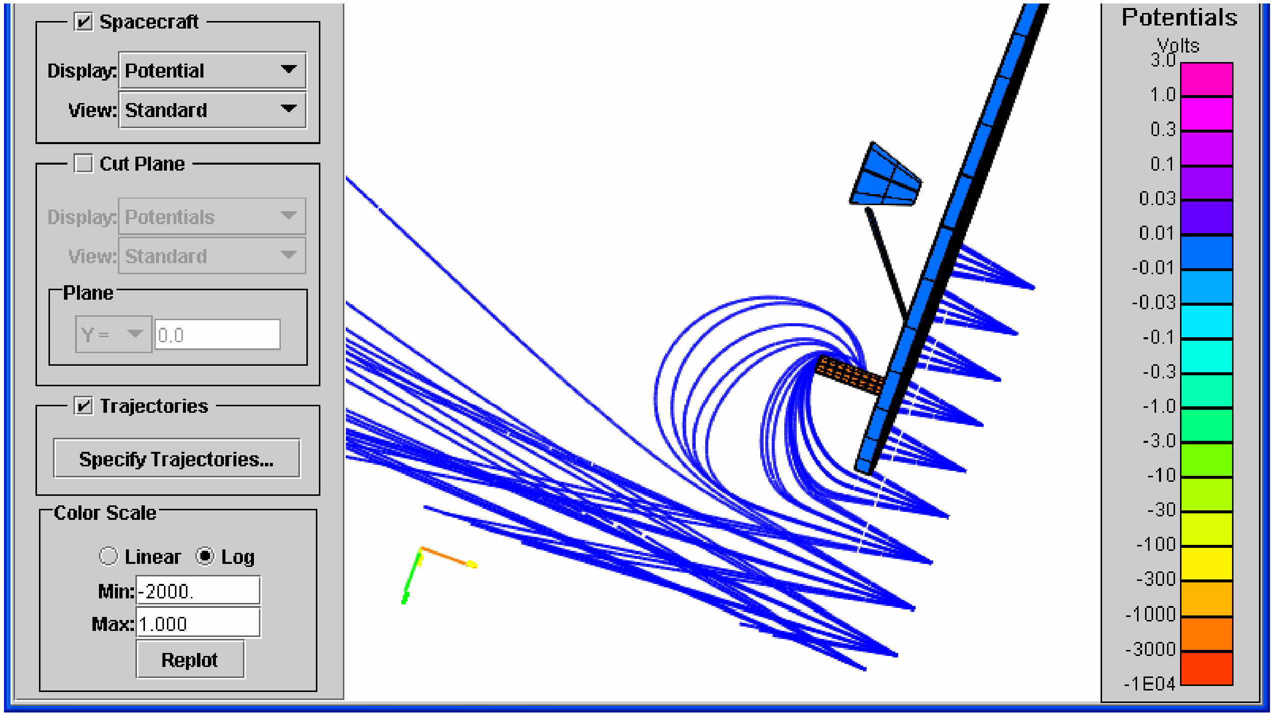
LEO Current Collection (IV)
Selected Particle Trajectories

- Ions generated at problem boundary with thermal spread about ram velocity
- Ions strike probe at tip or on far side



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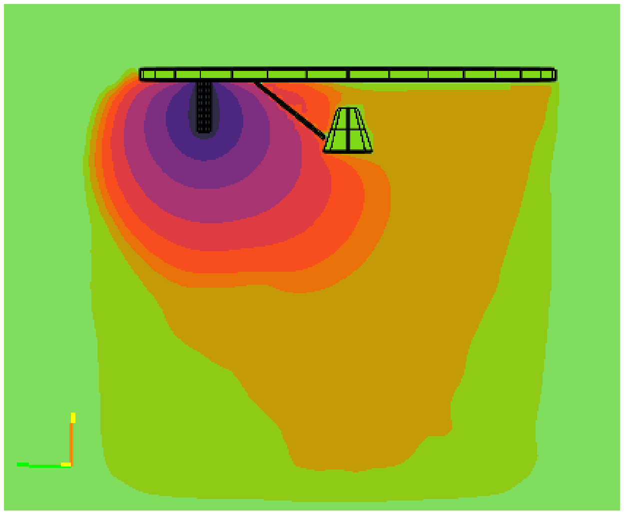
LEO Current Collection (V)

Orbit Averaged Particle-In-Cell

- Macroparticle charge distributed over trajectory sub-steps, allows longer timesteps in dynamic calculations

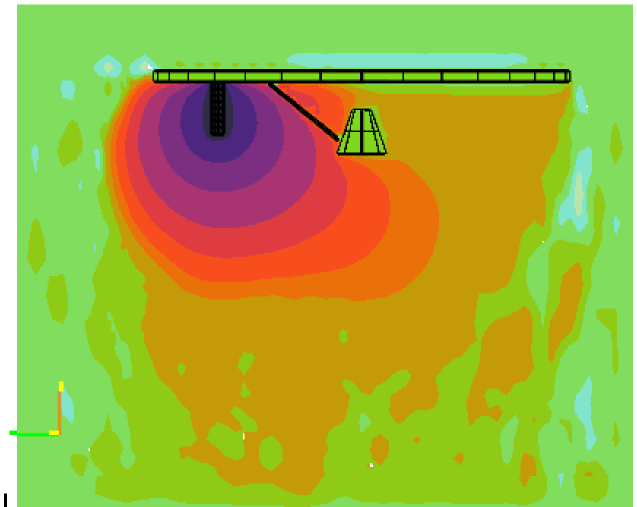


Full Trajectory (steady-state)

Macroparticles carry current

Share *current* $\times$ *sub-step time* to grid *each sub-step*

10 iters (with sharing) in 2 hours

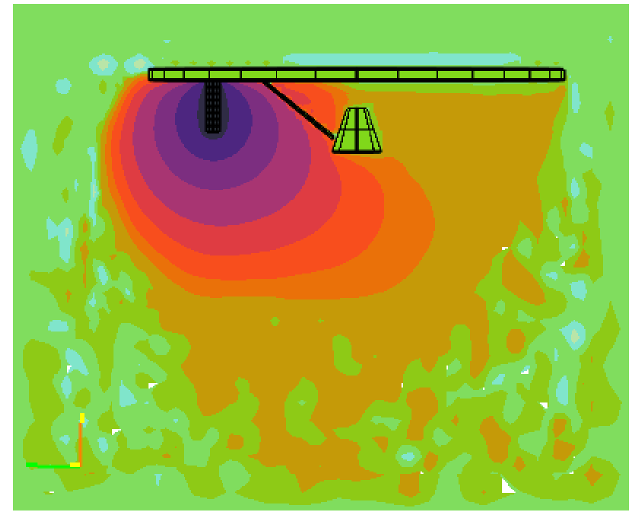


Particle-in-Cell (dynamic)

Macroparticles carry charge

Share *charge* to grid at end of *timestep*

900 2-μs timesteps in 140 hours



Orbit averaged

Macroparticles carry charge

Share $charge \times \frac{sub\text{-}step\ time}{timestep}$ to grid *each sub-step*

90 20-μs timesteps in 12 hours

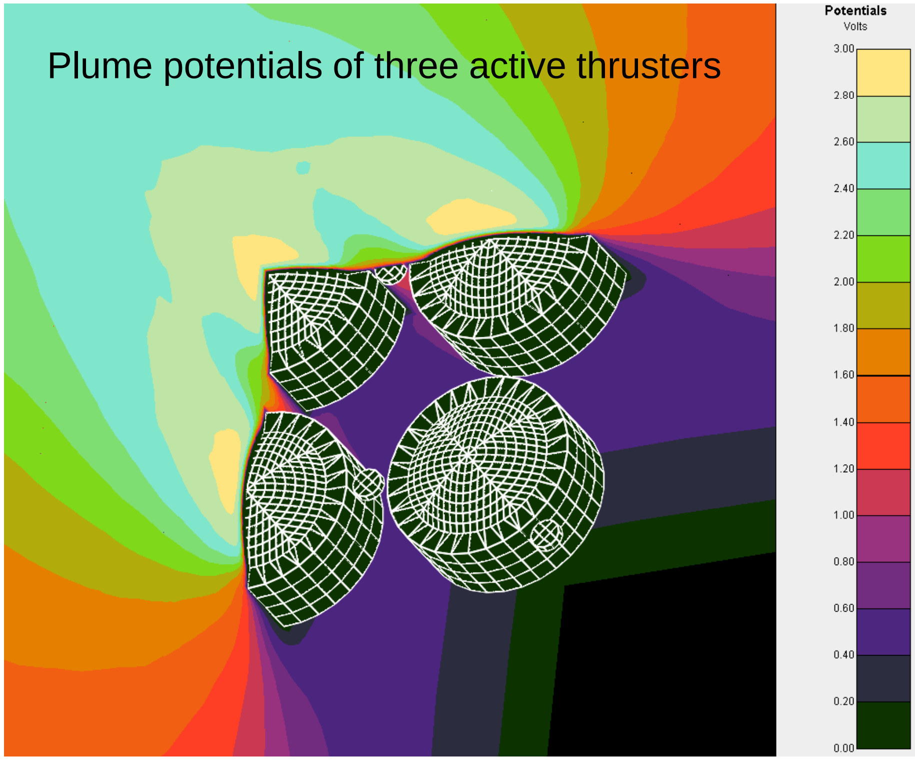
Acronyms defined on last slide

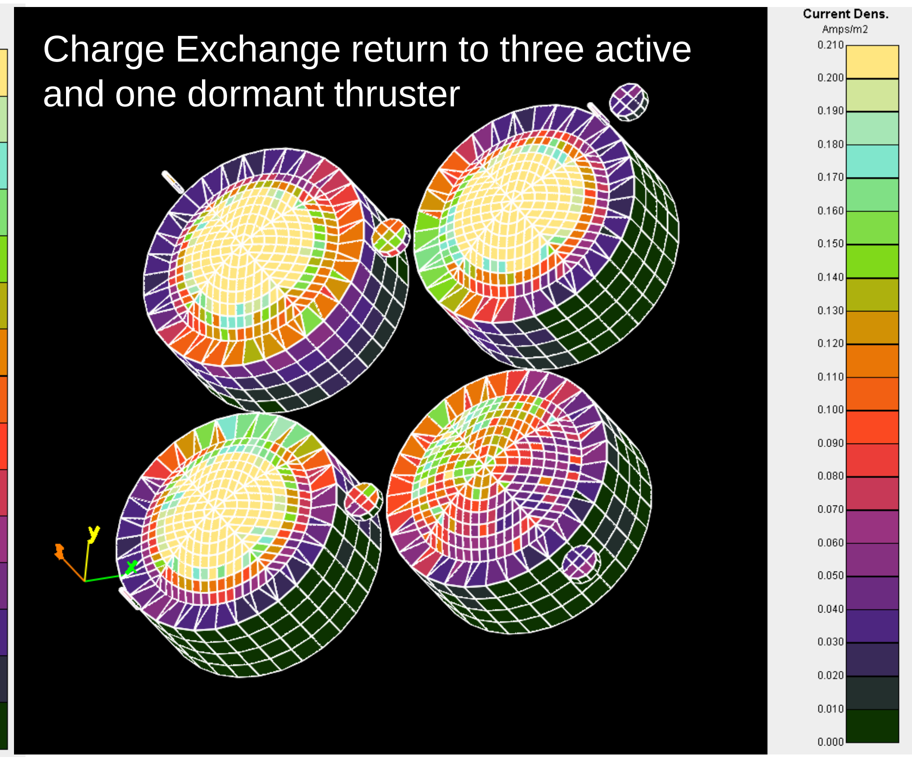
Potentials in Thruster Plumes (I)

- Thruster plumes
  - Produce potentials that modify contaminant trajectories
  - Produce charge-exchange ions that lead to enhanced plasma density around the spacecraft
  - Interact with spacecraft surfaces
  - Interact with other thruster plumes
- Import plume ion densities from external file
  - Densities created by *PlumeTool*, part of EPIC *(*Electric Propulsion Interactions Code, a NASA SEE (Space Environments Effects) product)
- Calculate potentials self-consistently with charge exchange ion generation and transport

Potentials in Thruster Plumes (II)

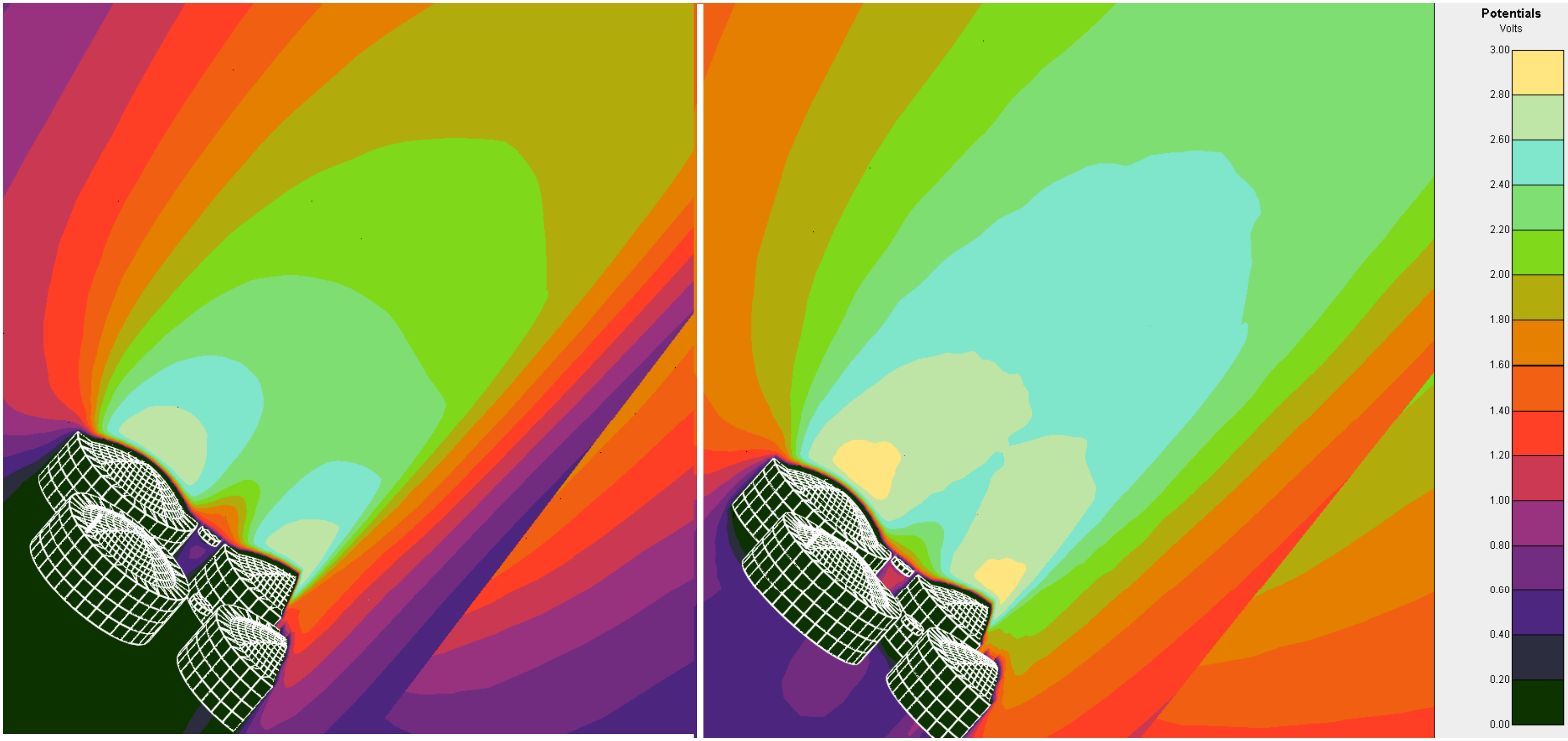
Charge-Exchange Ion Generation





- Used to calculate self-consistent interaction of ion thruster plumes with other plumes or spacecraft
- Used to simulate plume of NEXT Multi-Thruster Array
- Results published in *IEEE Transactions on Plasma Science*, 2008
- Implementation funded by NASA

Potentials in Thruster Plumes (III)
Space Versus Lab



Space Conditions

Lab Conditions

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Antenna-induced Currents (I)

- DSX (Demonstration and Science Experiments)
  - Air Force Research Laboratory experiment
  - High-voltage VLF (0.1-50 kHz) transmitter
  - Large oscillating sheaths
  - Poster papers
    - *Nascap-2k Self-consistent Simulations of a VLF Plasma Antenna*
    - *Pseudopotential Algorithms for Simulation of VLF Plasma Antenna Current Flow*
- Surface currents and volume electron currents obtained using pseudopotential methods
  - Consistent with *Nascap-2k* simulations and physically reasonable boundary conditions
- Volume ion currents obtained directly from PIC calculations
  - Enabled by capabilities of new database

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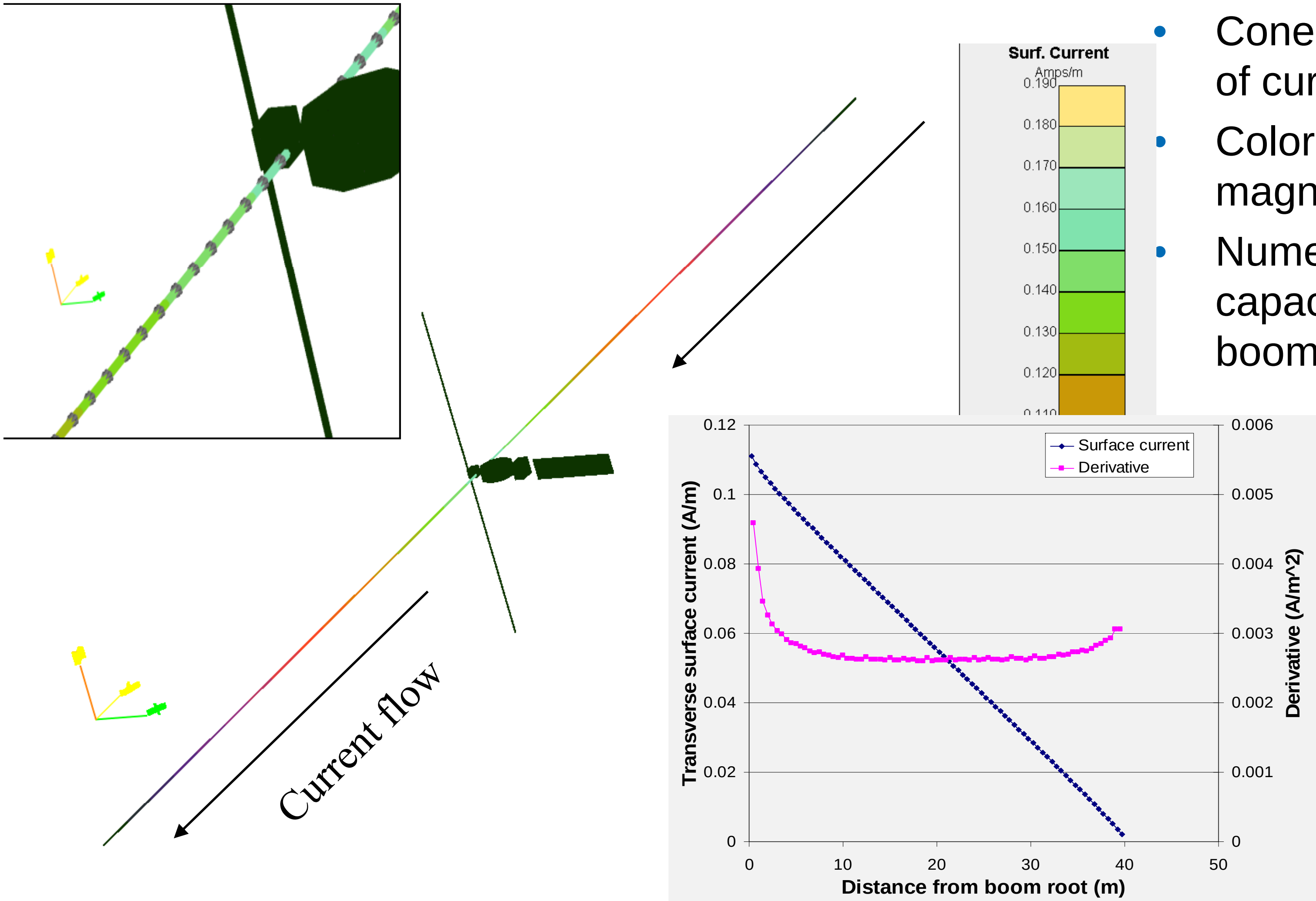
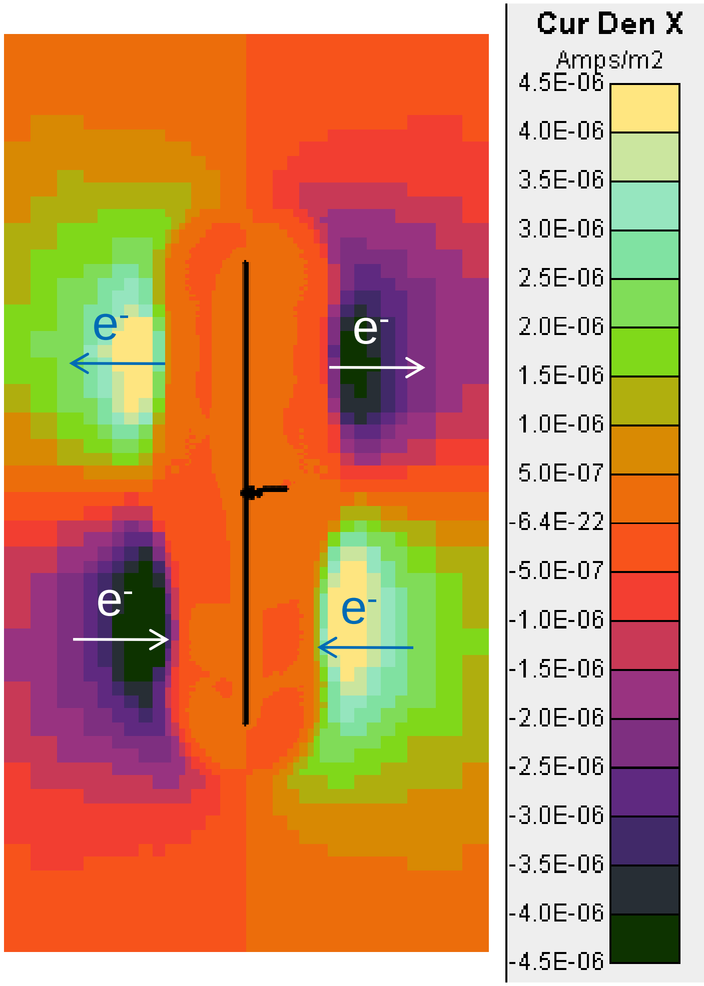
Antenna-induced Currents (II)
Surface Currents



- Cones indicate direction of current
- Colors indicate magnitude of current
- Numeric results show capacitive loading near boom root and tip

Antenna-induced Currents (III)
Volume Electron Currents

- Upper antenna sheath growing
  - Electrons moving away from antenna, indicated by currents toward antenna
- Lower antenna sheath shrinking
  - Electrons moving toward antenna, indicated by currents away from antenna
- Counterstreaming electron currents in cold plasma associated with whistler waves



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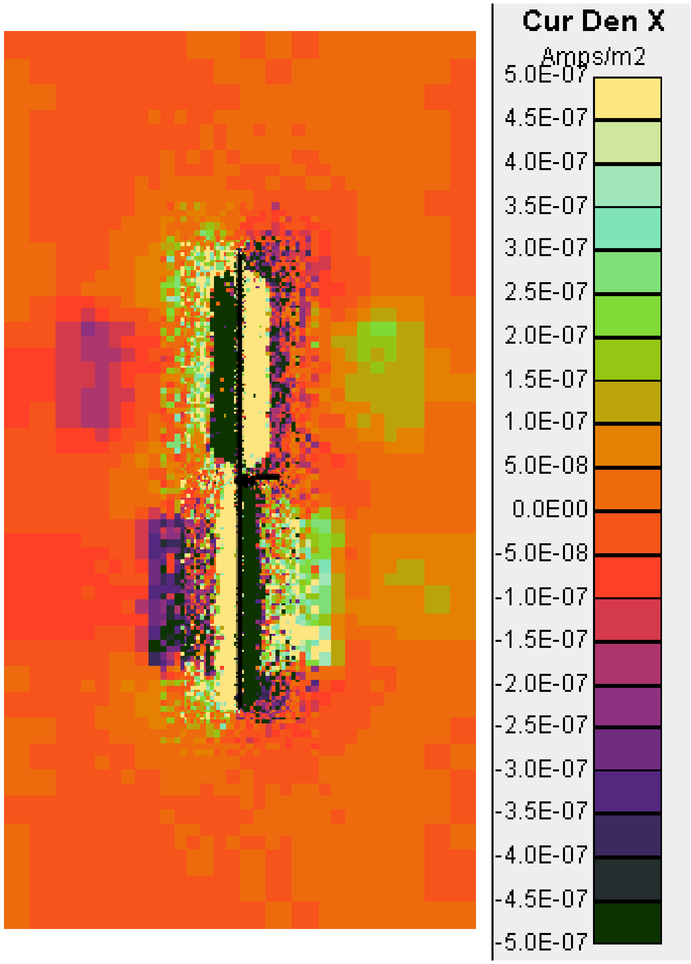
Antenna-induced Currents (IV)
Volume Ion Currents

- Obtained directly from PIC results
- Upper antenna
  - Just switched to near zero potential
  - Energetic ions that had been orbiting antenna are released and begin moving outward
  - Ions released during previous cycle are approaching grid boundary
- Lower antenna
  - Just switched to negative potential
  - Energetic ions released during near zero phase have moved into low field region of outer sheath
  - Stragglers are being reattracted to antenna by high fields



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Summary

- *Nascap-2k*
  - User-friendly integrated code
  - Study and analysis of a wide variety of spacecraft-plasma interactions
  - Variety of important space environments.
  - Uses efficient algorithms
  - Builds on heritage going back to late 1970s
- Examples presented
  - Charging in geostationary orbit
  - Current collection in low-Earth orbit
  - Charge exchange generation and potentials in thruster plumes
  - Surface and volume currents generated by antenna
- *Nascap-2k* is supported by Air Force Research Laboratory and the NASA Space Environments and Effects program
  - Distributed through http://see.msfc.nasa.gov

Acronyms

- CHAWS: Charge Hazards And Wake Studies
- GEO: Geosynchronous
- LEO: Low-Earth orbit
- MLI: Multi-layer insulation
- MSM: Magnetospheric Specification Model
- OSR: Optical Solar Reflector
- PIC: Particle-in-cell
- VLF: Very low frequency
- WSF: Wake Shield Facility