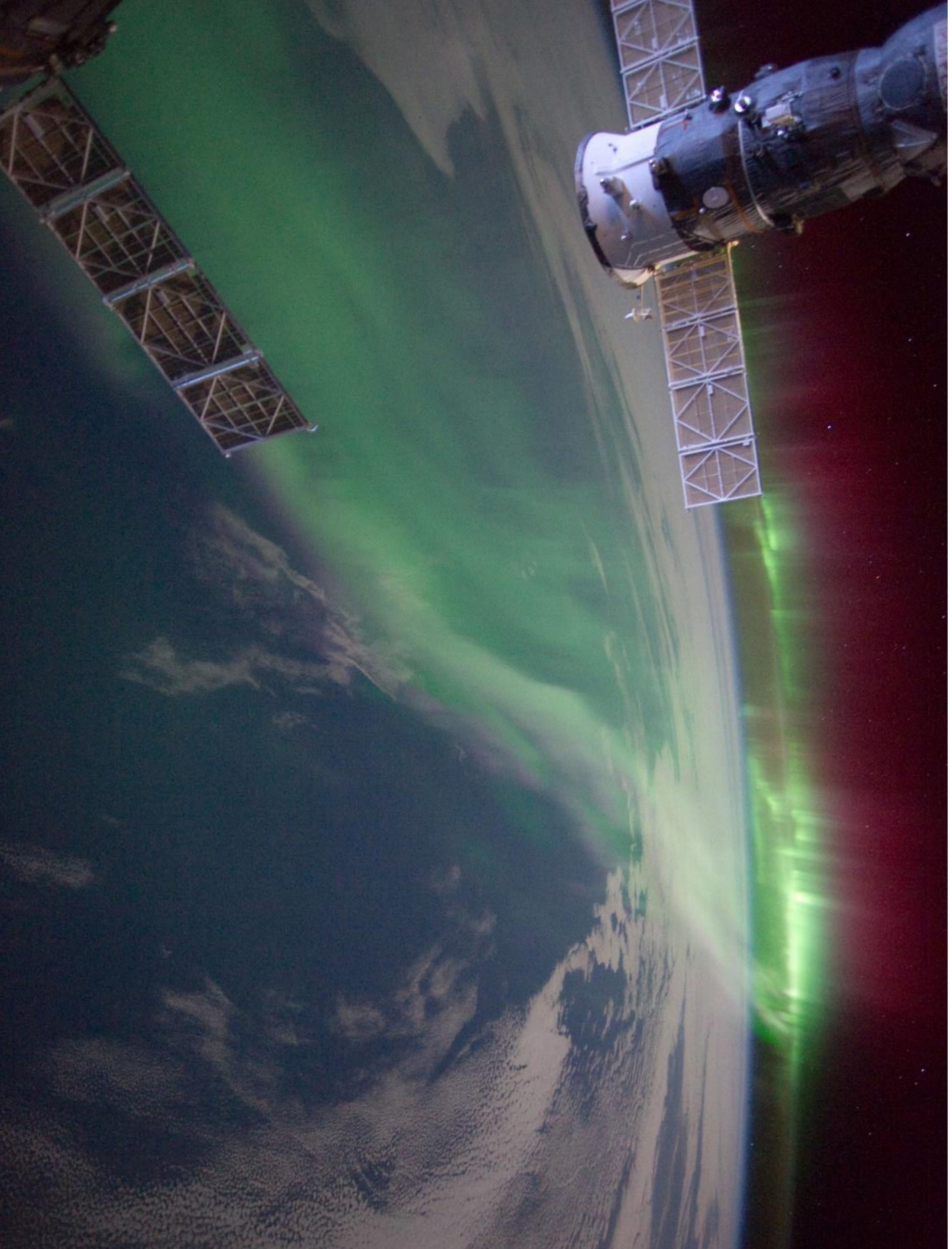

Spacecraft Charging Material Properties Database

Joseph I. Minow

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Linda Neergaard Parker

USRA, Huntsville, Alabama, USA

14th International Symposium on Materials in the Space Environment (ISMSE) and 12th International Conference on Protection of Materials from Space Environment (ICPMSE)

1 – 5 October 2018, Biarritz, France

Joseph.minow@nasa.gov

Introduction – Spacecraft Charging

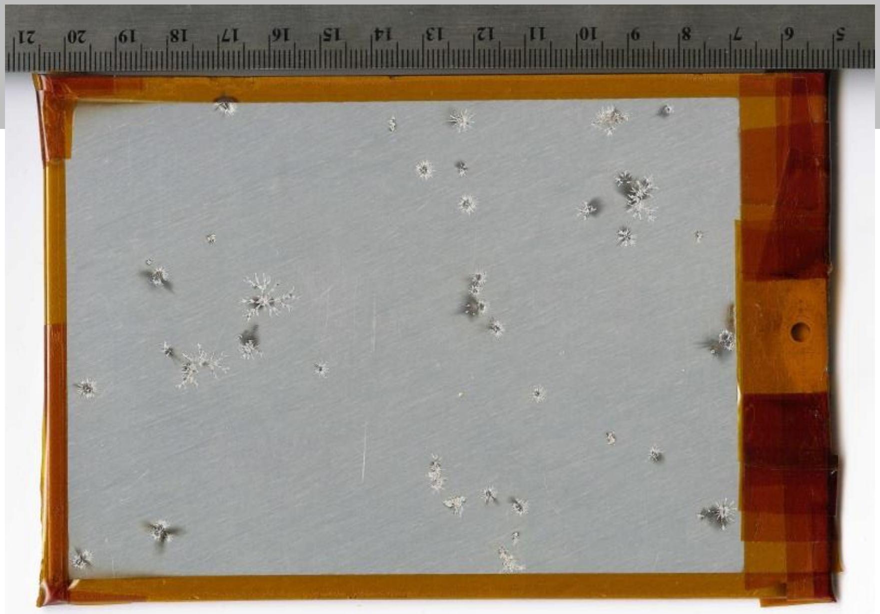
- Accumulation of excess negative charge generates potential differences between spacecraft ground and space (frame potential), between two points on the spacecraft surface or within materials (differential potential)

- An electrostatic discharge (ESD) results when electric fields associated with potential differences (**E** = $-\nabla\Phi$) exceed the dielectric breakdown strength of materials allowing charge to flow in an arc

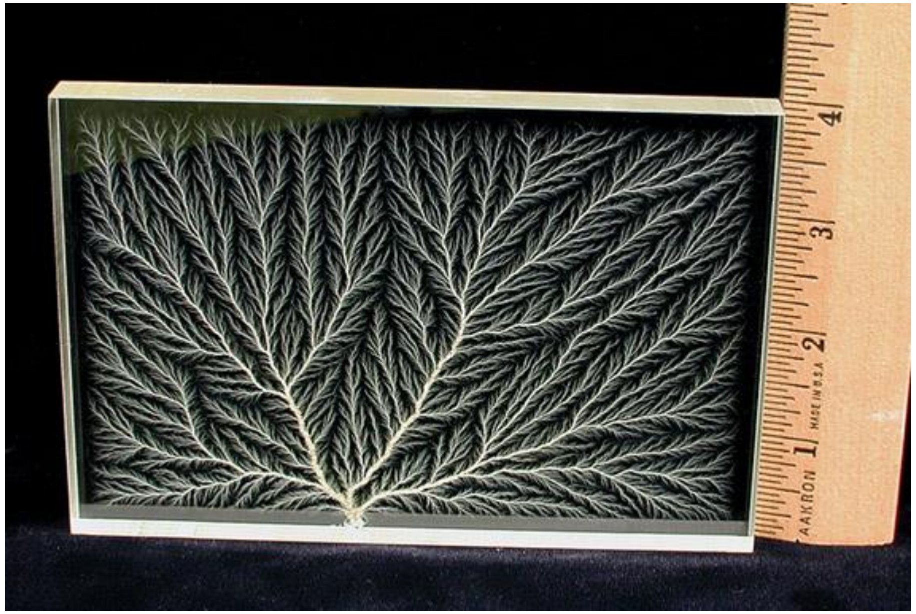
- Magnitude of damage depends on energy available to an arc

$$E = \frac{1}{2}CV^2$$

- Charging to a potential V depends on electrical properties of materials
  - Surface and volume resistivity
  - Dielectric constant
  - Secondary and backscattered electron yields, photoemission yields
  - Dielectric breakdown strength



ISS MMOD shield 1.3 μm chromic acid anodized thermal control coating (T. Schneider/NASA)



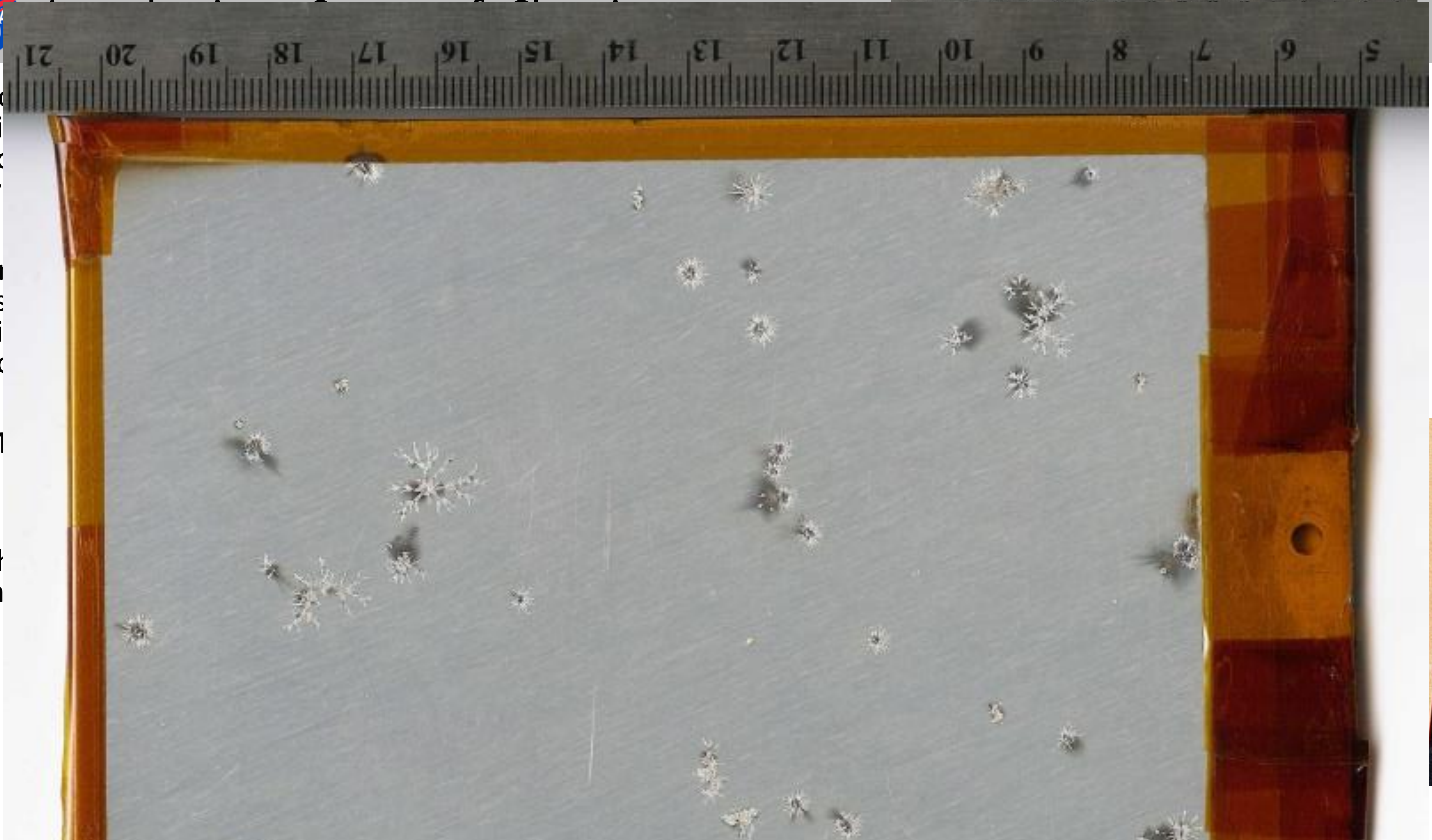
PMMA (acrylic) charged by ~2 to 5 MeV electrons

- Ad
di
po
w

- Ar
as
di
flo

- M

- Ch
m



Surface Charging

- Surface charging models solve for surface potentials and electric fields as a function of time dependent ion and electron currents to and from surface elements

$$\frac{\mathrm{dQ}}{\mathrm{dt}} = \frac{\mathrm{d\sigma}}{\mathrm{dt}}\mathrm{A} = \mathrm{C}\frac{\mathrm{dV}}{\mathrm{dt}} = \sum_j I_k$$

where

$$\frac{\mathrm{dQ}}{\mathrm{dt}} = \sum_j I_k = +I_i(V)$$ **incident ions**

$$-I_e(V)$$ **incident electrons**

$$+I_{bs,e}(V)$$ **backscattered electrons**

$$+I_c(V)$$ **conduction currents**

$$+I_{e,se}(V)$$ **secondary electrons due to I_e**

$$+I_{i,se}(V)$$ **secondary electrons due to I_i**

$$+I_{ph,e}(V)$$ **photoelectrons**

$$+I_b(V)$$ **active current sources including charged article beams, thrusters**

and $\mathrm{J} = \sigma E + k_{RIC}\left(\frac{dS}{dt}\right)^x$

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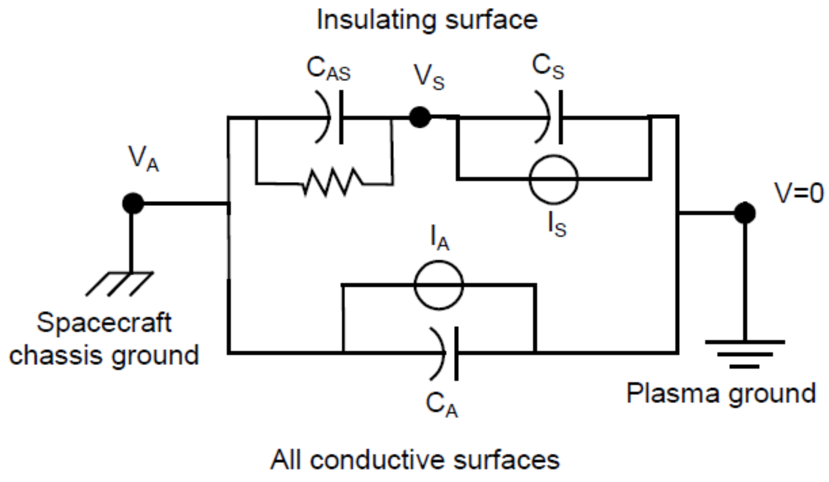

$$C_{AS} = \kappa\varepsilon_0\frac{S}{d} \sim S \; x \; 10^{-6}\, F$$

$$C_A \sim C_S = 4\pi\varepsilon_0 R\left(\frac{S}{4\pi R^2}\right) \sim \frac{S}{R} \; x \; 10^{-11} F$$

$$\mathbf{C_A\dot{\Phi}_A + C_{AS}(\dot{\Phi}_A - \dot{\Phi}_S) = I_A}$$

$$\mathbf{-C_{AS}(\dot{\Phi}_A - \dot{\Phi}_S) + C_S\dot{\Phi}_A = I_A}$$

$$\mathbf{C\dot{\Phi} = I(\Phi)}$$

[*Davis and Mandell*, 2015]

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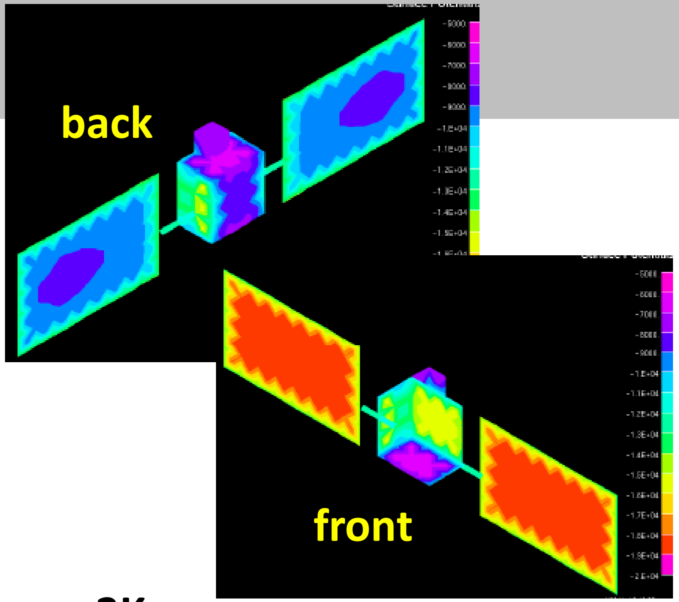
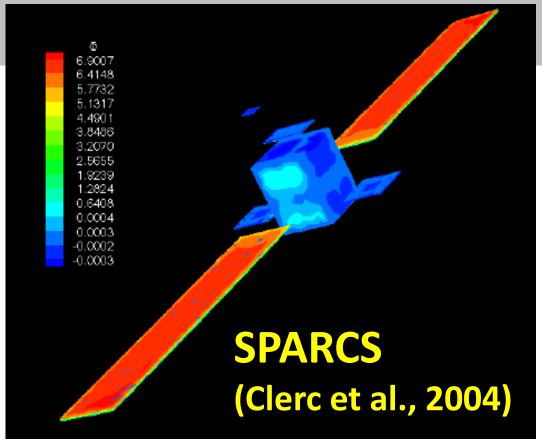
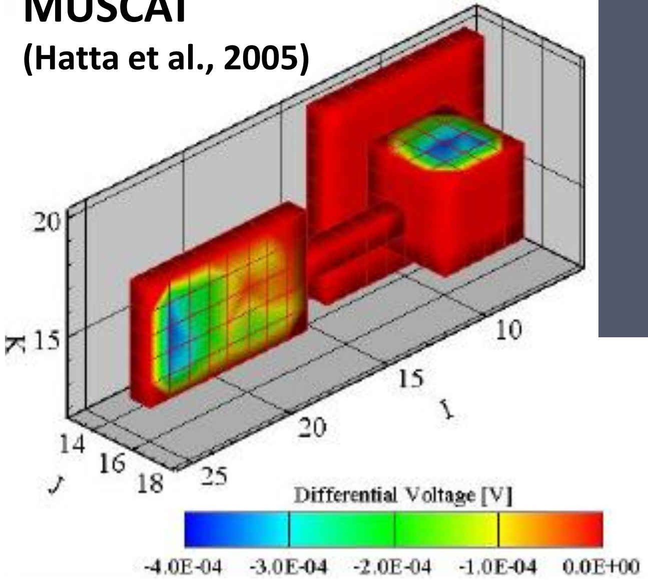
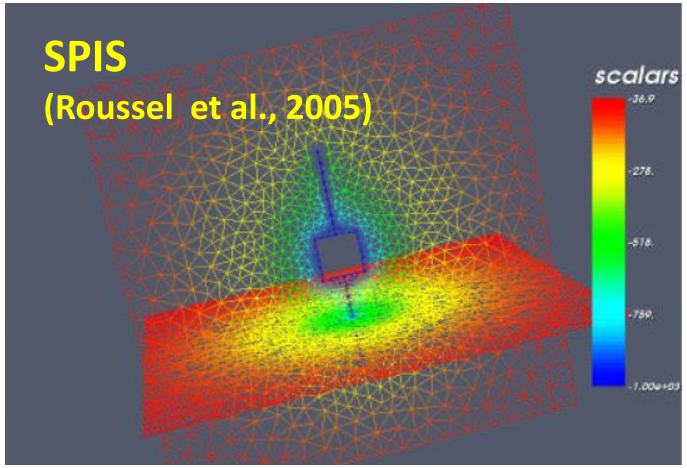


Nascap-2K
(Neergaard et al., 2001)



MUSCAT
(Hatta et al., 2005)





Internal Charging

- Internal charging models solve coupled radiation transport and electrostatic equations to obtain time dependent potentials and electric fields within materials exposed to penetrating electrons
- Radiation transport depends on material properties
  - Density
  - Atomic number
  - Atomic mass
- Electrostatics

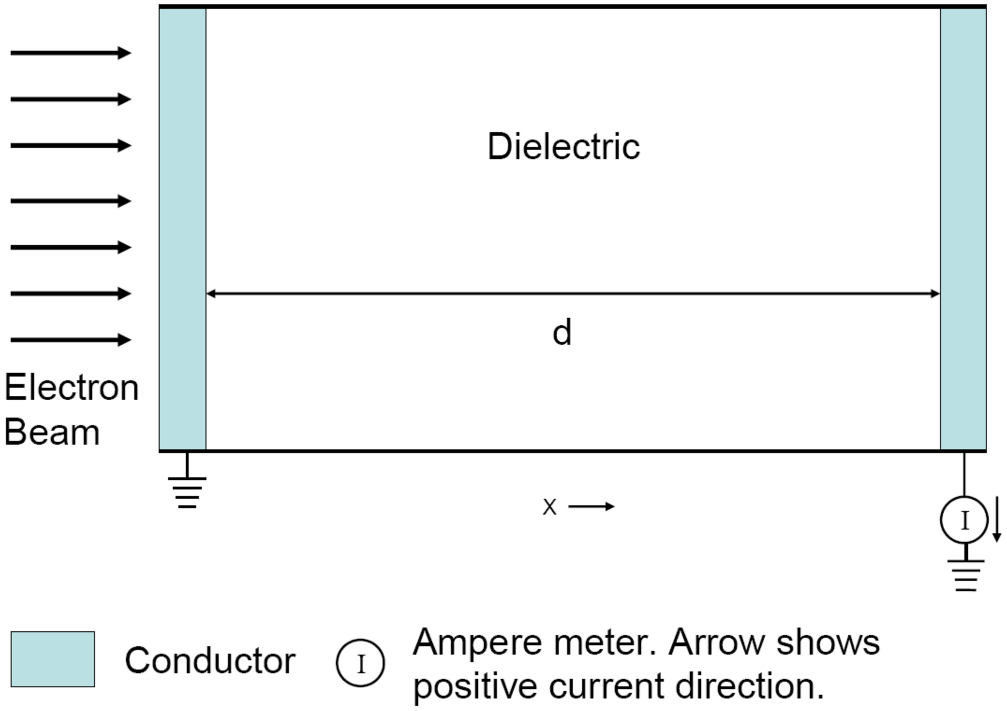
$$\vec{\nabla} \cdot \vec{D} = \vec{\nabla} \cdot \varepsilon\vec{E} = \vec{\nabla} \cdot \kappa\varepsilon_0 \left(-\vec{\nabla}\phi\right) = \rho$$

$$\nabla^2\phi = -\rho/_{\kappa\varepsilon_0}$$

$$\frac{\partial\rho}{\partial t} = -\vec{\nabla} \cdot \vec{J}$$

where $J = J_{conduction} + J_{radiation}$

$$= \sigma E + k_{RIC}\left(\frac{dS}{dt}\right)^x$$



[*Jun et al.* 2007]

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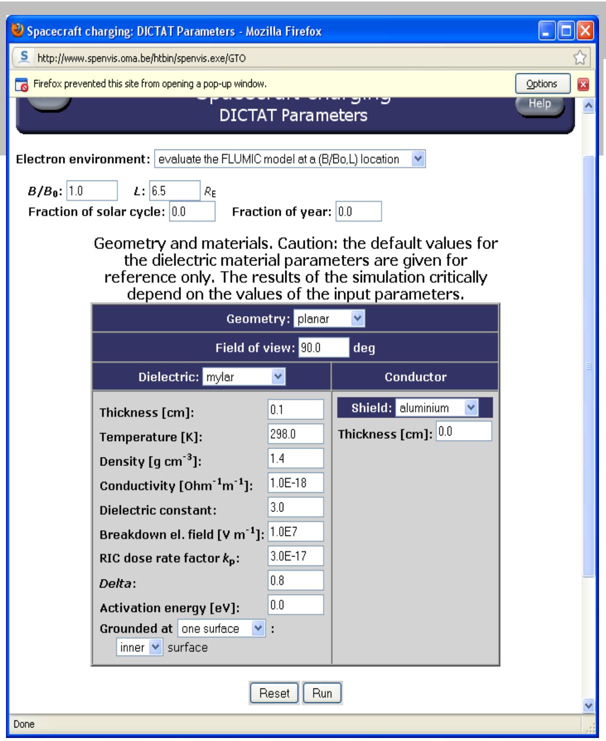
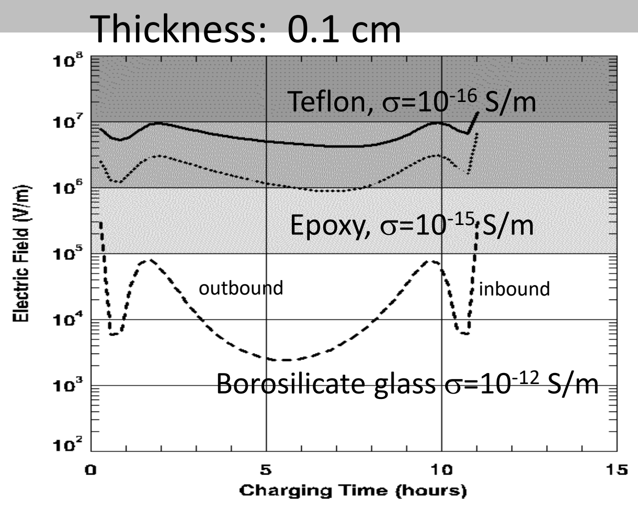
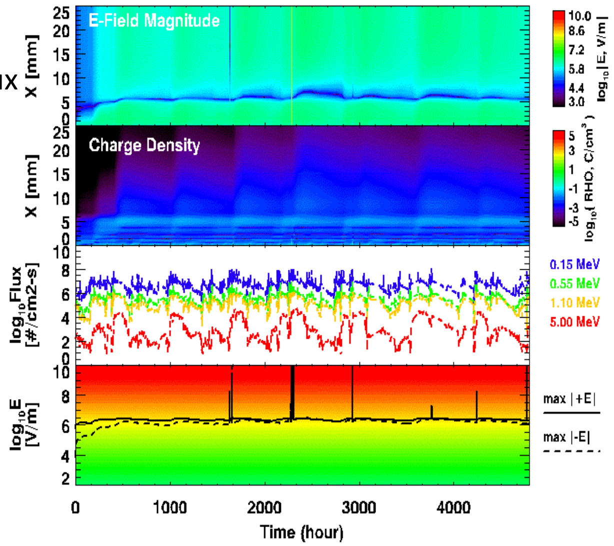




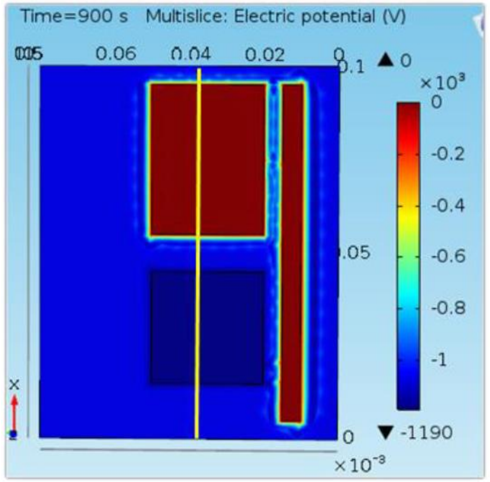
DICTAT (1-D model)
http://www.spenvis.oma.be/

Charging current
Electron energy, flux from LANL-01A

Material
PMMA
Z=6, A=12
~2.5 cm thick
$\sigma \sim 1 \times 10^{-17}$ S/m
$\kappa = 2.00$
$\rho = 1.0$ g/cm^3



NUMIT (1-D model)



NUMIT 3-D
Kim et al., 2018

Spacecraft Charging Materials Database (SCMD)

Electrical Properties

New Record

NOTIFICATION 1

home

help

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Materials exposed to the space environment will accumulate charge due to the differential collection of ion and electron currents from the space radiation and plasma environment. The magnitude of the electric fields, electric potentials, and electric potential gradients generated by an excess charge density on (or in) a material is an important consideration for space system design and operations. Accumulation of a significant localized charge density can lead to electric fields exceeding the electrostatic breakdown strengths of materials, resulting in electrostatic discharges which are responsible for a number of detrimental effects including material degradation, electromagnetic interference, and even catastrophic failure of sensitive electronic components in extreme cases.

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SCMD Template NASA-HDBK-4002

NASA-HDBK-4002A

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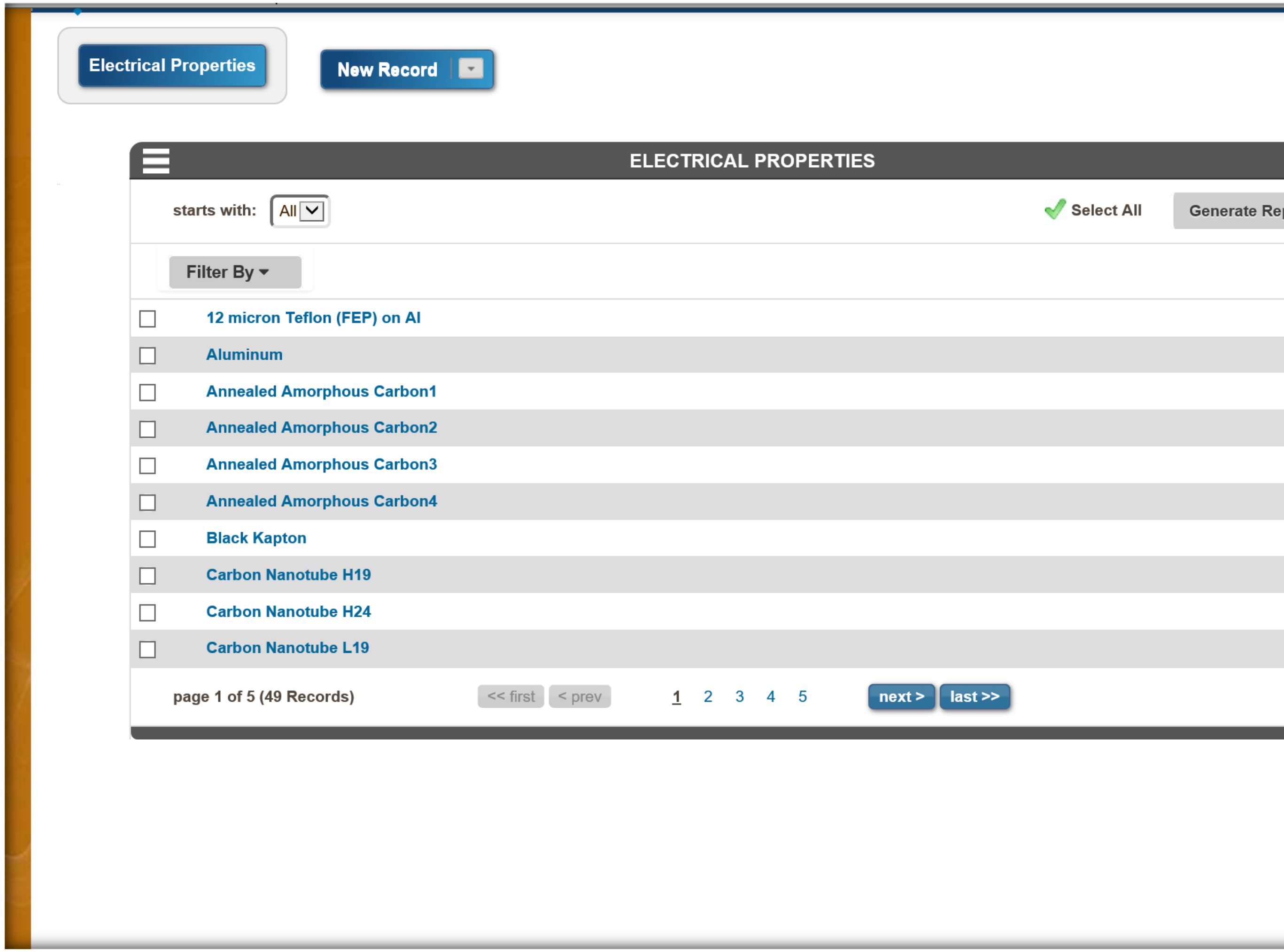
SCMD Template **NASA-HDBK-4002**

NASA-HDBK-4002A

SCMD – Electrical Properties of Materials

- Database currently holds information on 49 materials
  - NASCAP default materials
  - Utah State University test results



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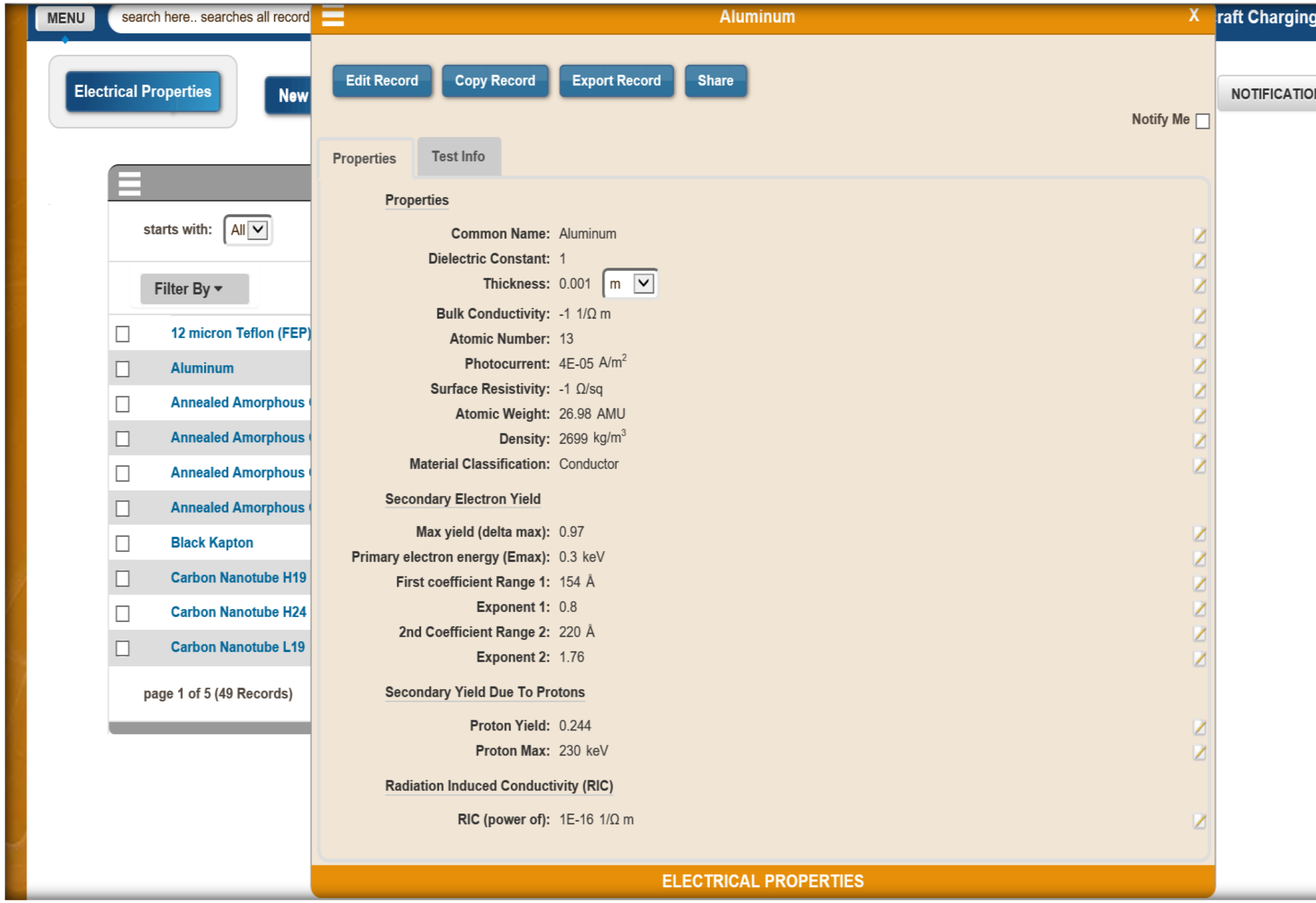

SCMD – Test Information

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  - NASCAP default materials
  - Utah State University test results
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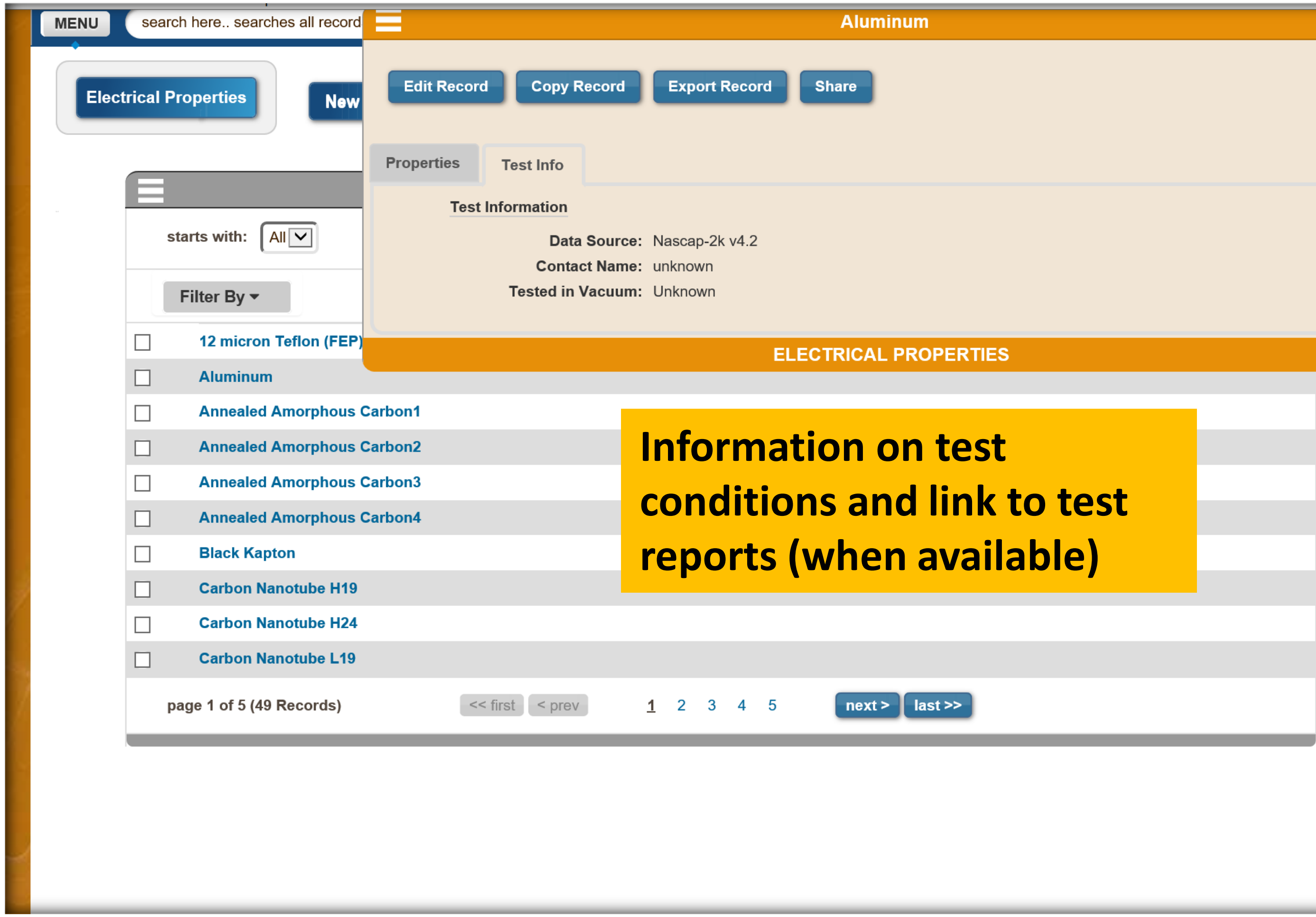
- Information on test conditions and links to test reports



SCMD – Search Option

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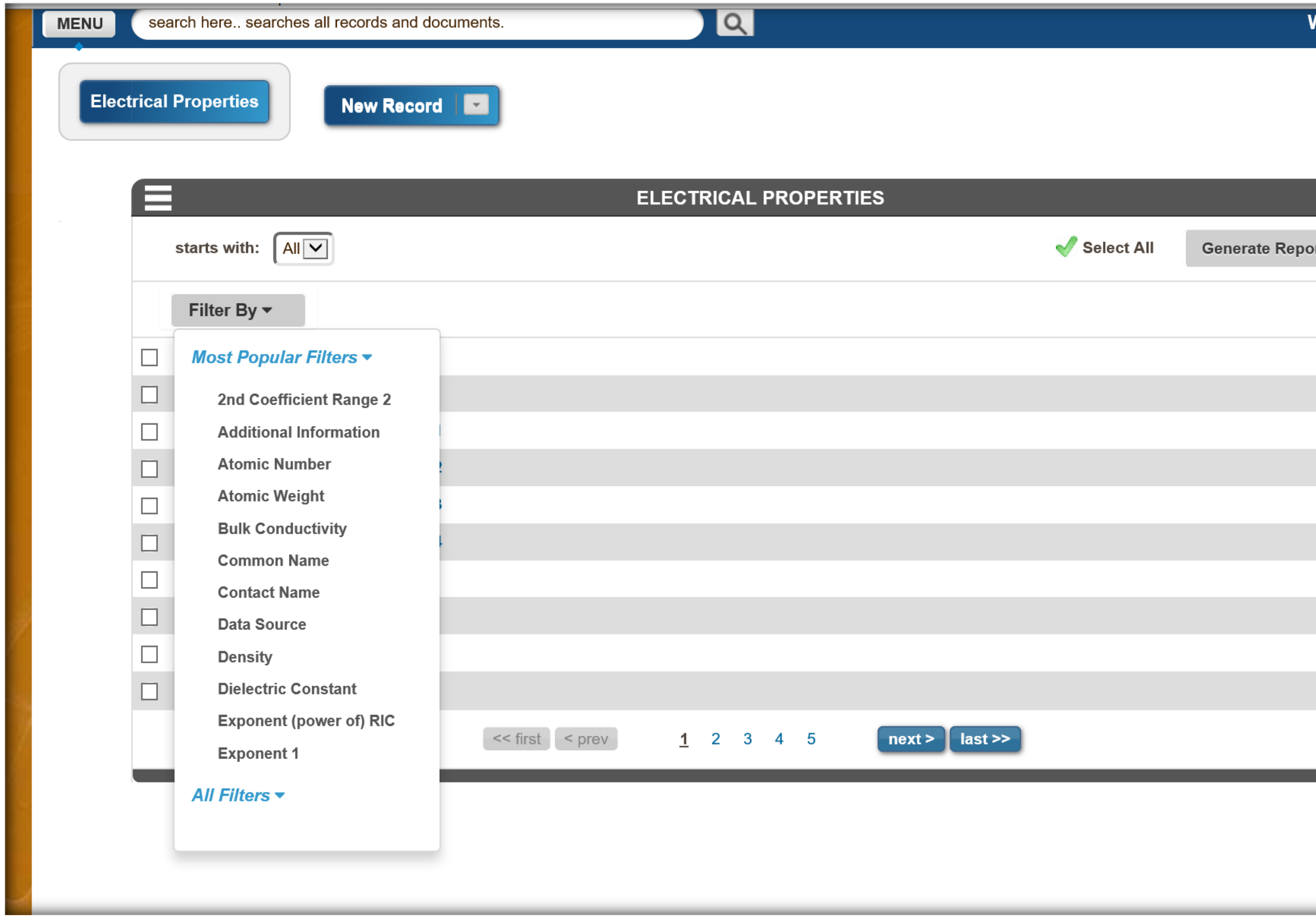
- Search options
  - Exact search match
  - Checking to see if can be "part" of word



SCMD – Other Features

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- Search options
  - Exact search match
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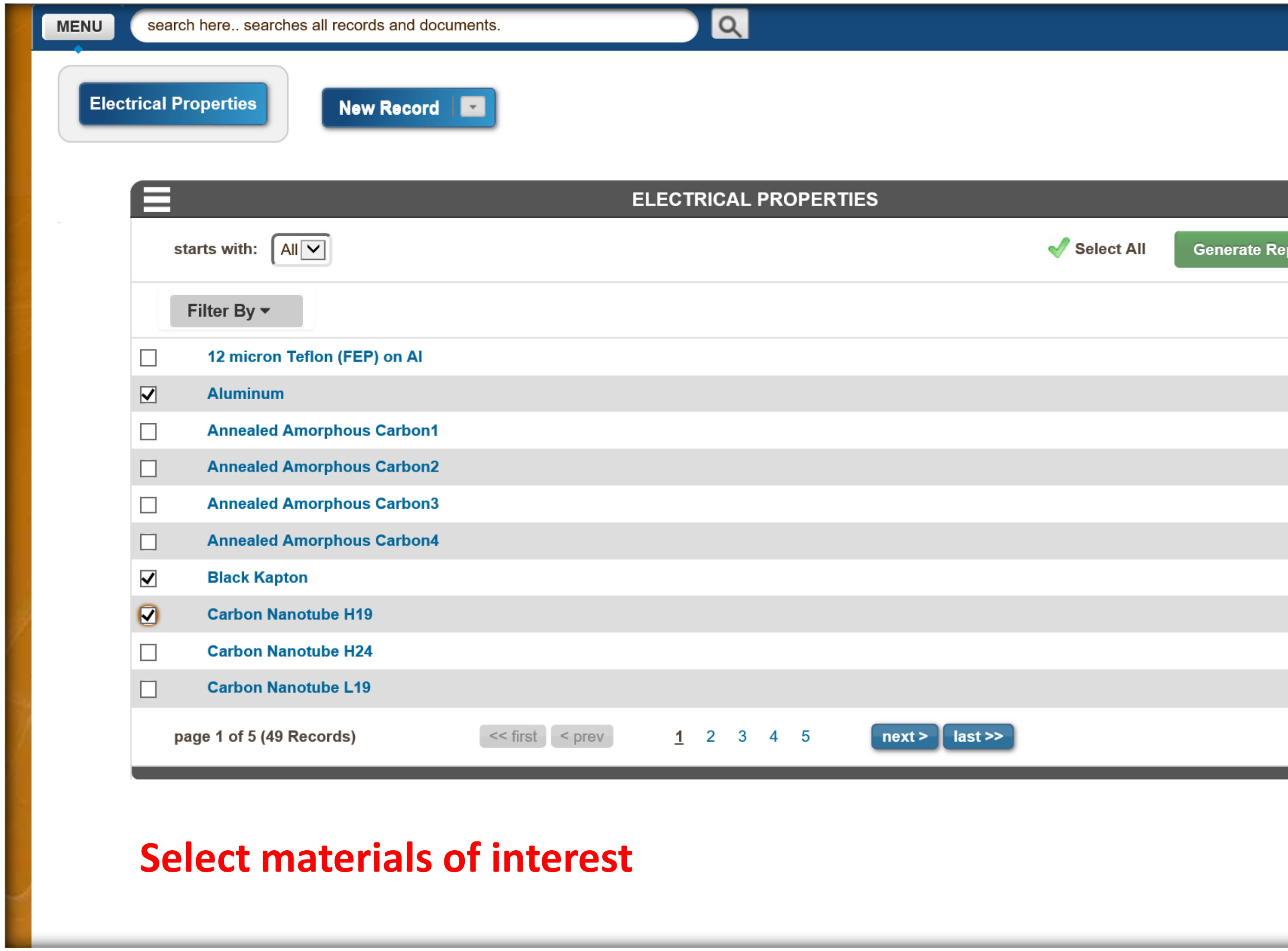
- Other features include
  - Export records of selected materials to a variety of external file formats
  - Generate reports on user selected material properties
  - Generate plots



Select materials of interest

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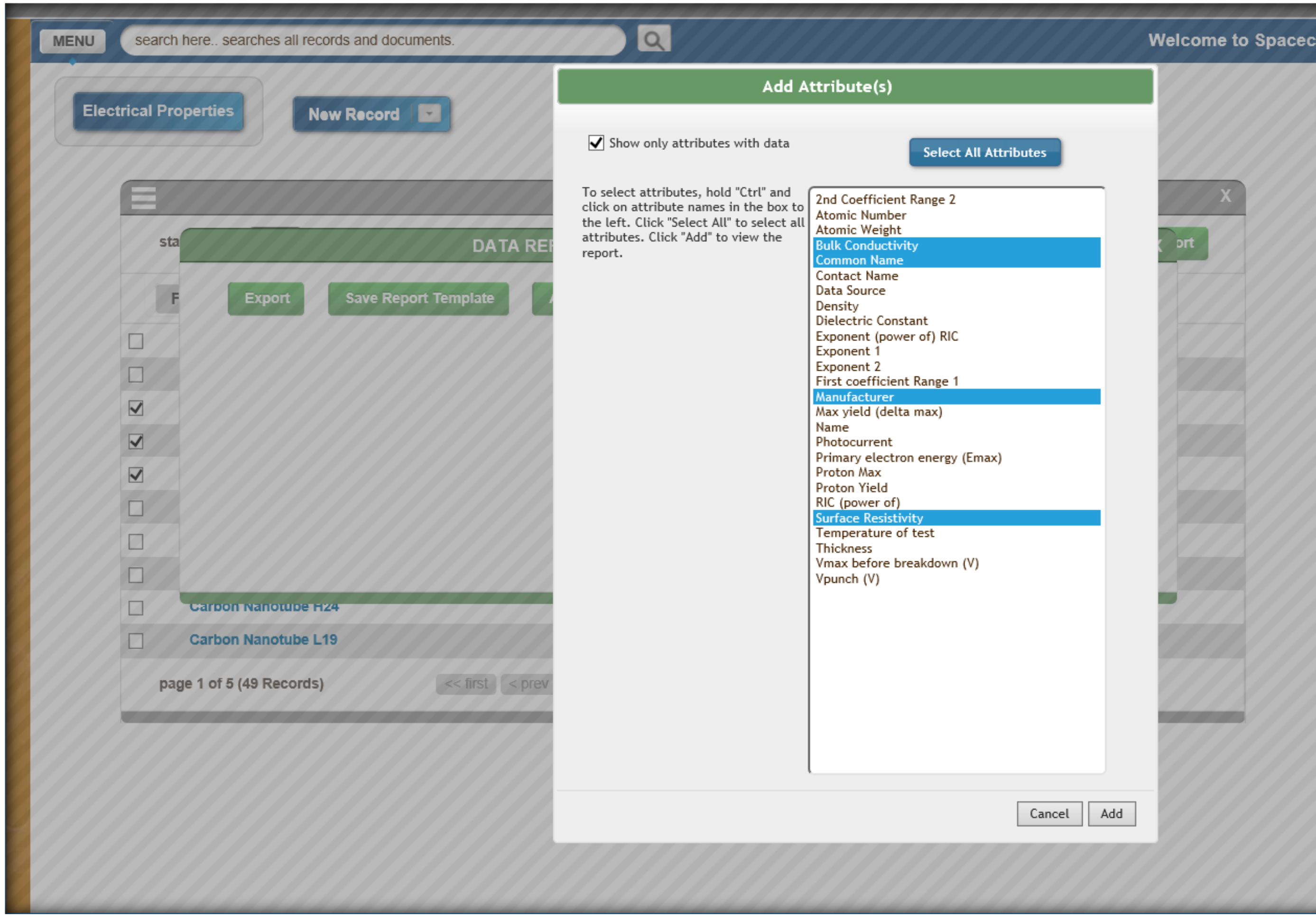

Select material properties of interest

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SCMD Template **NASA-HDBK-4002**

NASA-HDBK-4002A

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SCMD Template **NASA-HDBK-4002**

NASA-HDBK-4002A

SCMD Input Template....adding data to the database

- Template required to submit information to SCMD administrators
  - Excel® spreadsheet format
  - Input parameters must be in units given in spreadsheet
  - -9999 for no information or missing data

						Secondary Electron Yield			
Common Name	Manufacturer	Dielectric Constant	Thickness (m)	Bulk Conductivity (1/Ohm m)	Atomic Number	Max Yield (delta max)	Primary electron energy (Emax (keV))	First coefficient Range (A)	Exponent 1

- Input parameters
  - Dielectric constant
  - Secondary electron yield coefficients due to incident electrons and ions
  - Bulk conductivity
  - Surface resistivity
  - Test reports and information on testing parameters

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SCMD Template NASA-HDBK-4002

NASA-HDBK-4002A

Charging Reports, Handbooks, Standards, Guidelines

NASA

- Purvis et al., Design Guidelines for Assessing and Controlling Spacecraft Charging Effects, NASA-TP-2361, 1984.
- NASA-HDBK-4002 – Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects, 1999
- NASA-HDBK-4002A, Mitigating In-Space Charging Effects – A Guideline, 2017
- NASA-STD-4005A, Low Earth orbit Spacecraft Charging Design Standard, 2016
- NASA-HDBK-4006A, Low Earth Orbit Spacecraft Charging Design Handbook, 2007
- NASA-HDBK-4007, Spacecraft High-Voltage Paschen and Corona Design Handbook, 2016
- SLS-SPEC-159, Cross-Program Design Specification for Natural Environments (DSNE), Revision E, 2017

Other? (TBD)

- MIL-STD-1809, Handbook for the USAF Space Environment Standard, PL-TR-93-2010, 1993
- ECSS-E-ST-20-06C, Space Engineering: Spacecraft Charging, ESA, 2008
- JERG-2-211A, Design Standard, Spacecraft Charging and Discharging, JAXA, 2012

Spacecraft Charging Material Database Access

- Database is available on-line at the address https://maptis.ndc.nasa.gov/scmd

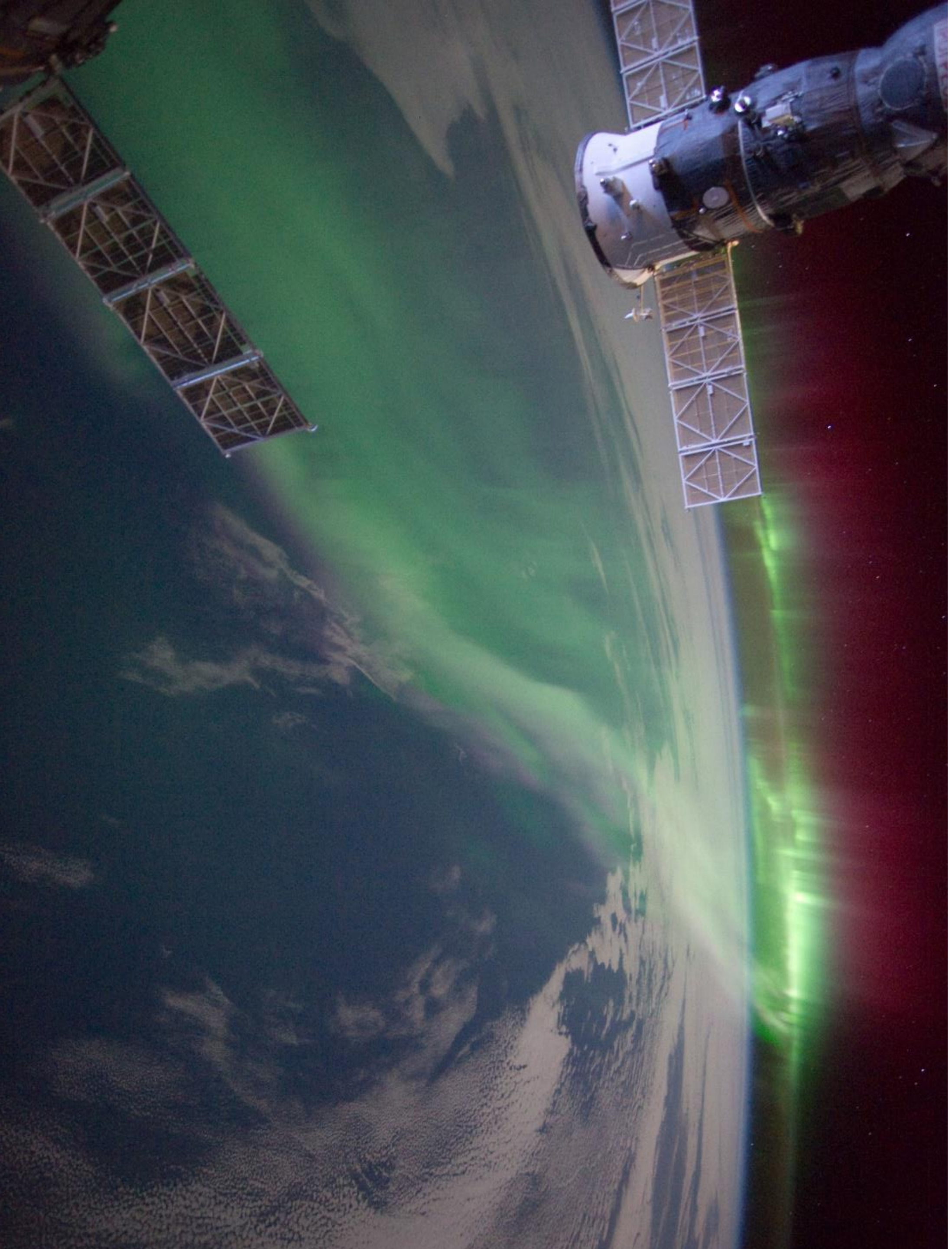
- SCMD is open to public use with free registration
  - Contact POCs for access request form
  - No export controlled or proprietary information allowed in the database

- Adding new materials
  - Material property contributions from the community are welcome and requested!
  - Template required to add materials, forward to POCs

- Please provide comments and suggestions for improvements to POCs!

- Point of contact (POC):

Linda Parker lparker@usra.edu
Joseph Minow joseph.minow@nasa.gov



Questions?

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