

G4 Geomagnetic Storm
23-24 April 2023



Recommendations from the ISWAT G3 Surface Charging Paper

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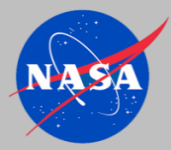
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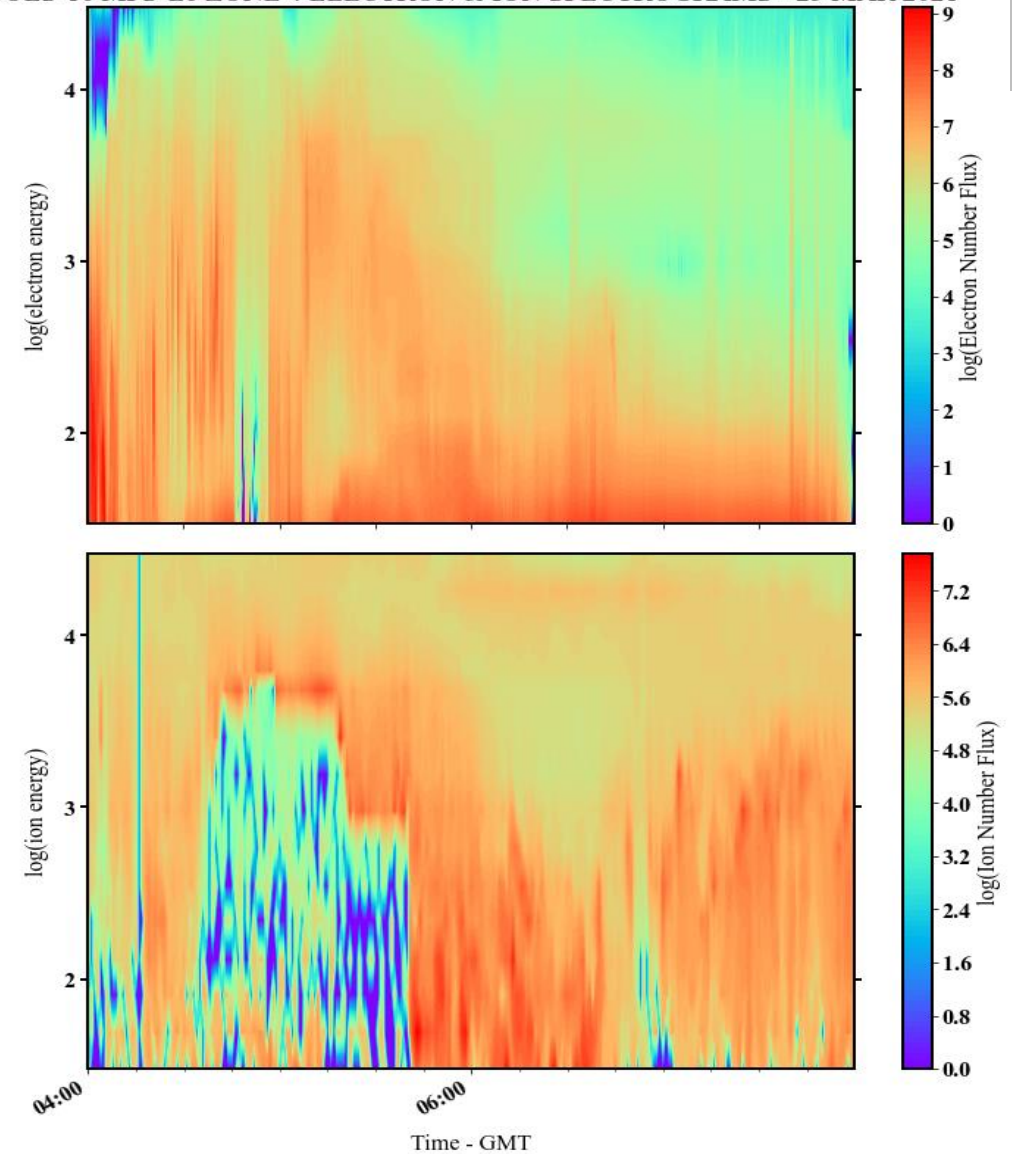
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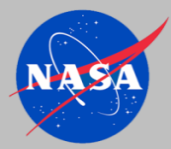
Outline

- **Energetic charged particles in the natural space environment** are responsible for surface charging, internal charging, single event effects, and total dose hazards for spacecraft materials and avionics systems.
- **Surface charging by electrons at ~keV energies** remains a hazard to spacecraft operations because accumulation of excess charge densities on spacecraft surfaces can result in electrostatic discharges, damaging materials and coupling large currents into sensitive and vulnerable circuits.
- **Surface charging hazards continues to be of great relevance today** due to the continual evolution of human exploitation of space environments in terms of:
 - Number of satellites launched (e.g., large constellations)
 - Technologies used in spacecraft design
 - Manufacturing techniques used to build spacecraft
 - Use of novel orbits in significant charging environments
- **This presentation summarizes the recent surface charging review contributed to the COSPAR Space Weather Roadmap** with particular emphasis on the near- and long-term recommendations provided in the paper to improve the spacecraft charging discipline.

GOES-16 MPS-Lo ZONE 4 ELECTRON & ION SPECTROGRAMS - 25 MAR 2021



GOES-16 surface charging during eclipse on 25 March 2021



Summary of COSPAR ISWAT G3 Surface Charging Paper

- **The paper is an overview of a community-driven effort focused on surface charging** coordinated by COSPAR's International Space Weather Action Team (ISWAT) on "*Surface Charging Effects and the Relevant Space Environment*"
URL: <https://iswat-cospar.org/G3-02>
- **Paper in final stages of review with publication expected for 2024**
- **Electrostatic discharge (ESD) damage to spacecraft due to surface charging is an old and well understood threat** that has plagued spacecraft manufacturers and operators for many years - seemingly having been "*engineered*" out and therefore deemed to no longer be a problem several times.
- **Surface charging continues threaten space systems due to**
 - Modern spacecraft design teams with little or no experience in spacecraft charging mitigation techniques
 - Mission designs utilizing orbital environments with significant charging threats
 - Spacecraft construction problems including material selection and grounding issues that leave a spacecraft vulnerable to ESD from surface charging

G3: Near-earth radiation and plasma environment

<https://iswat-cospar.org/g3>

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Impact: (Aero)Space Assets Functions

- **Surface charging**
- Internal charging
- Single Event Effects (SEE)
- Total dose
- Human health
- Aviation safety
- Astronauts health at LEO orbits

Action Teams:

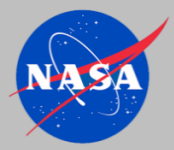
G3-01: Radiation Effects at Aviation Altitudes (Lead: Kent Tobiska Matthias Meier)

G3-02: Surface Charging Effects and the Relevant Space Environment (Lead: [Natalia Ganushkina](#) [Joseph Minow](#) [Dave Pitchford](#) [Vania Jordanova](#))

G3-03: On total dose effects (Lead: Insoo Jun Timothy Guild)

G3-04: Internal Charging Effects and the Relevant Space Environment (Lead: Yuri Shprits Paul O'Brien)

G3-05: Solar Energetic Particle Population in Geospace (Lead: [Valeriy Tenishev](#))

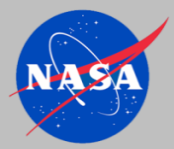


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iSWAT Spacecraft Surface Charging Review (Outline of Paper)

- 1) Introduction
- 2) Background and Historical Context
- 3) Surface Charging Environments
- 4) Space Weather Models Relevant for Surface Charging
- 5) Charging Indices and Metrics
- 6) Surface Charging Analysis Tools
- 7) Conclusions and Future Directions



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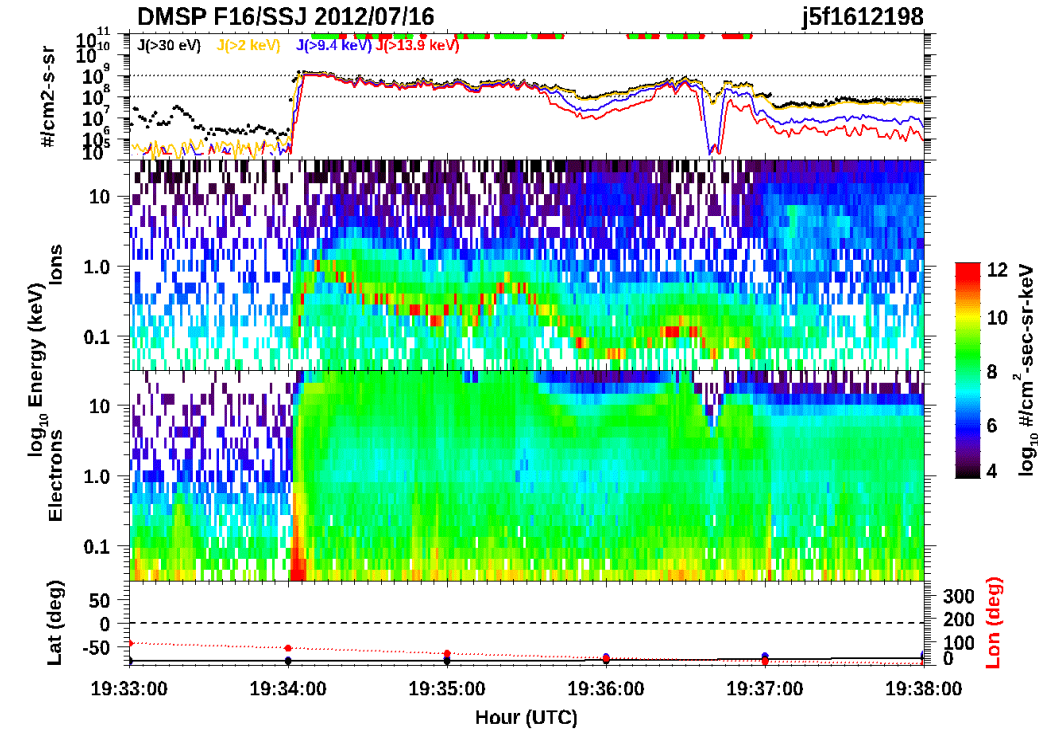
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Section 7 contains recommendations for addressing surface charging in

- Surface Charging Observations
- Space Weather Models
- Charging Indices and Metrics
- Surface Charging Analysis Tools
- General Recommendations

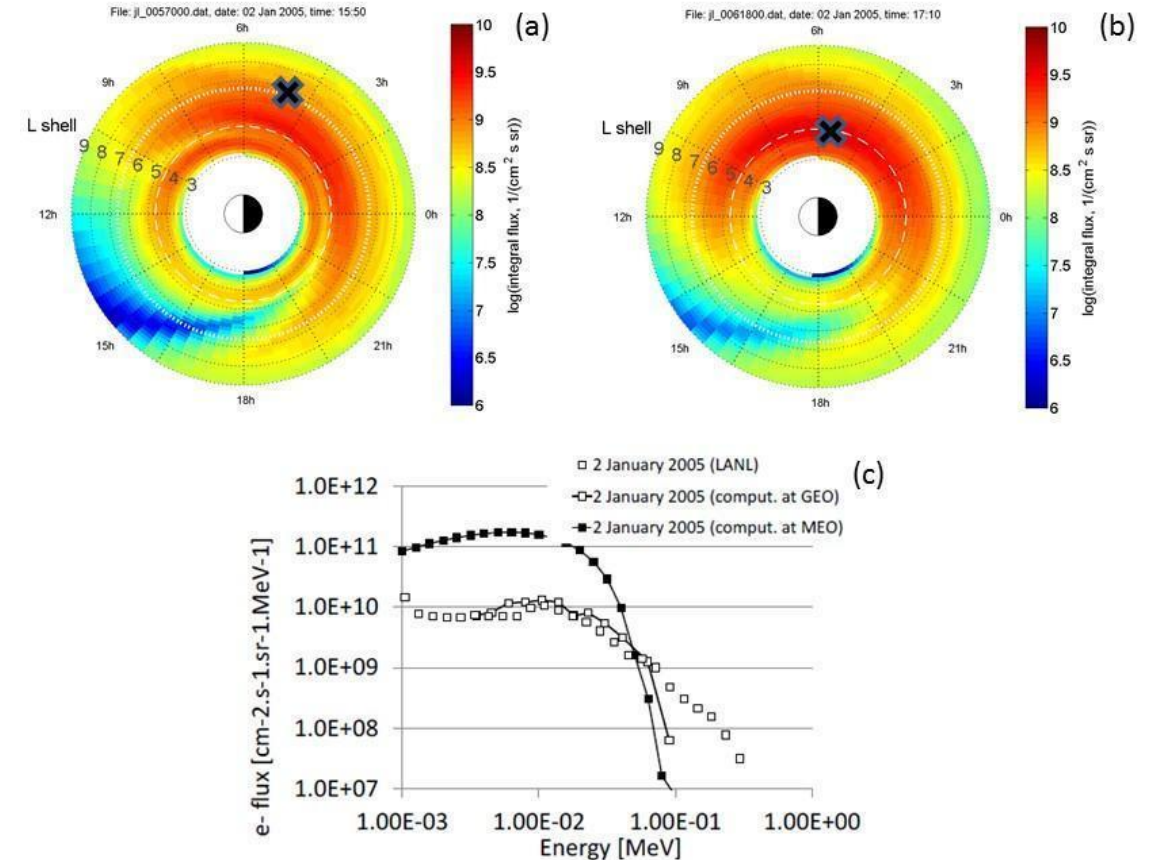
Surface Charging Observations

- **Additional charging observations in terms of environmental conditions and spacecraft surface potentials in widely used orbits are needed** including geostationary orbit, low Earth polar orbits, medium Earth orbits over a wide range of inclinations, and non-traditional orbits that are finding increasing use by the commercial space industry.
- **Near-term opportunities to improve access to data on surface charging** includes a) deploying charging sensors on more spacecraft, particularly for spacecraft in orbits with only minimal information and b) working with holders of proprietary data such as the Lockheed CPA sensors to share this information with the science and engineering community.
- **Long term recommendations for obtaining a more complete picture of the spatial and temporal variations in charging environments and satellite response** are a) deploying small charge sensors on all spacecraft operating in significant charging environments and b) sharing the data through a clearing-house open to the research community.



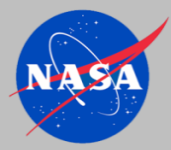
DMSP surface charging to ~1 kV

- **Recommend more testing and validation of space weather models to reproduce the near-Earth space environment.**
- **Recommend modelers adopt as a near-term goal (with the next 5 years) to improve environment models by generating outputs in formats used by common engineering tools (e.g., *Nascap-2k*) to address user community needs.**
- **Recommend modelers address as long-term goals:**
 - a) The lack of adequate models for the cold particle populations, as well as auroral charging conditions, that are critical gaps that will need more effort to be retired,
 - b) Transitioning the space weather models to operations,
 - c) Improving communication and collaboration between space environment scientists and the spacecraft charging community to develop more reliable space weather forecasting tools to maintain the orderly operation of spacecraft as the number of missions increase.



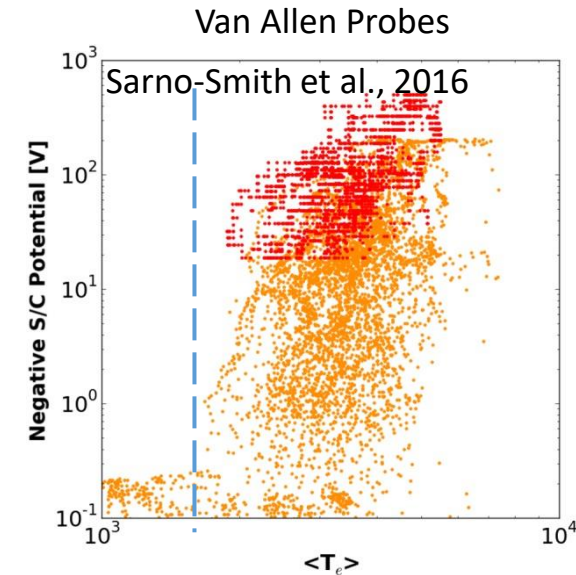
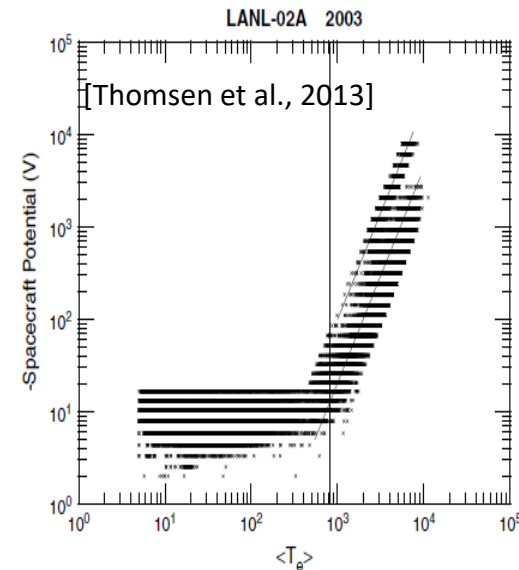
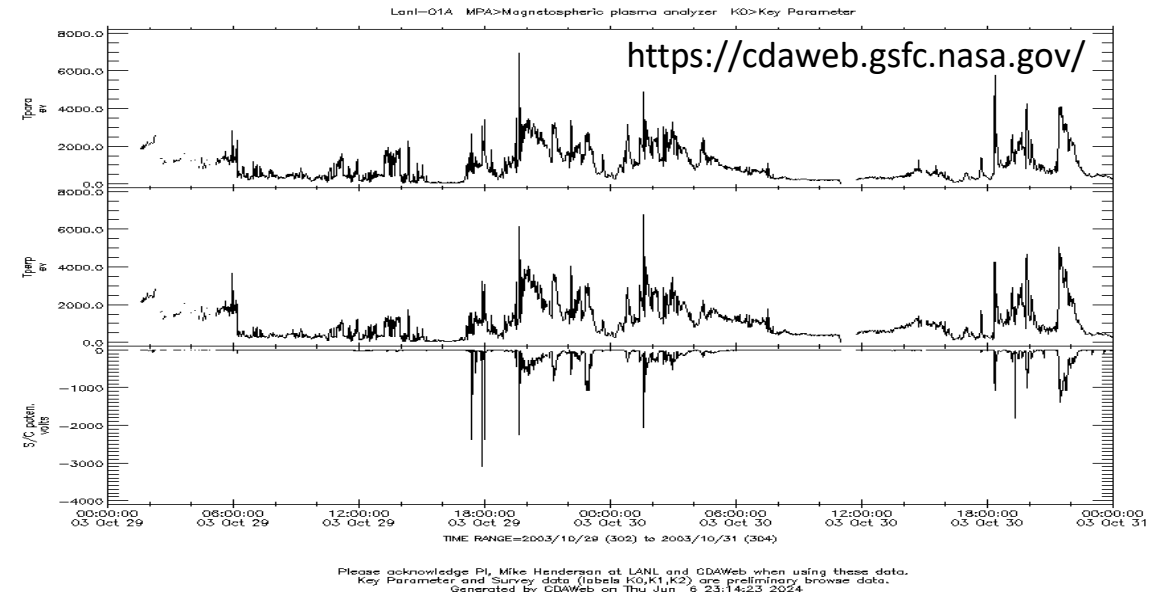
IMPTAM Model 1-100 keV Electron Flux

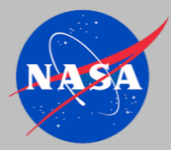
- (a) Worst-case severe environment for surface charging detected at GEO
- (b) When the electron flux reached its peak at MEO



Charging Indices and Metrics (1/2)

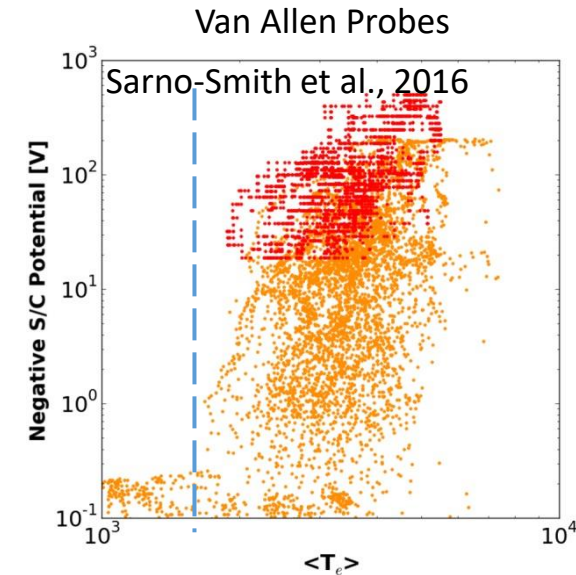
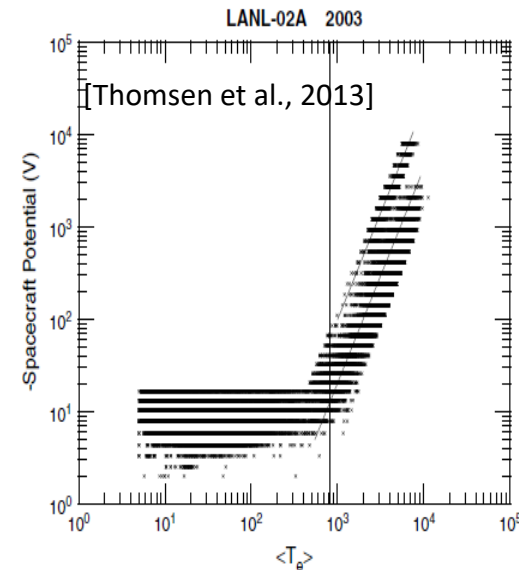
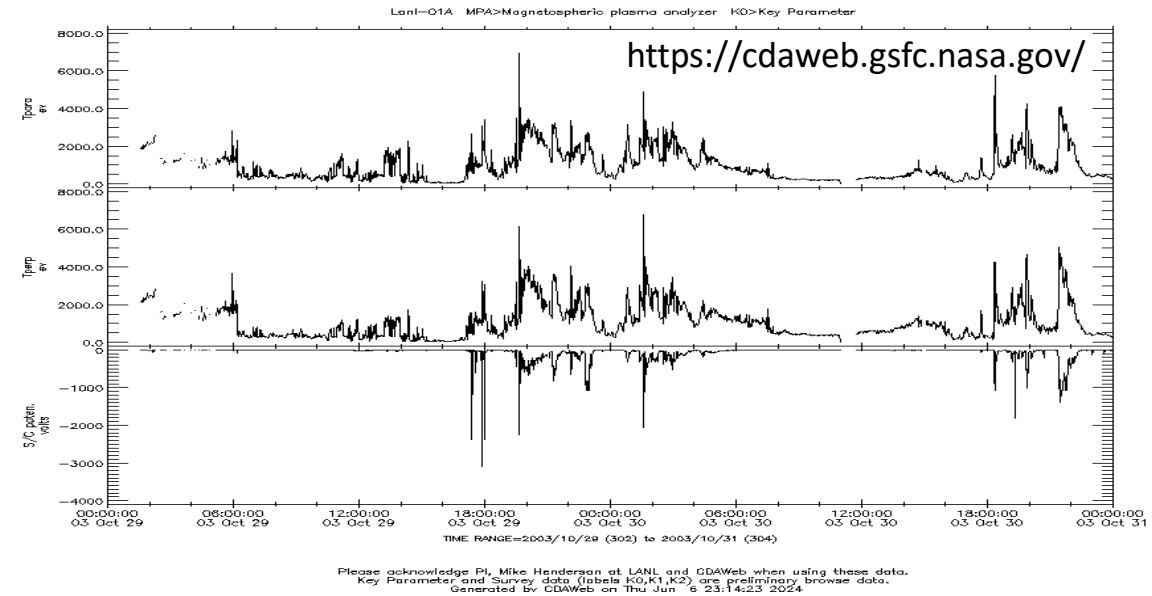
- **Metrics including >10 keV electron flux**, the integral flux between about 10 keV to 50 keV (exact values can be flexibly adjusted to some extent depending on available measurements' energy channels and coverage), **or average electron temperature $\langle T_e \rangle$ should continue to serve as the Essential Space Environment Quantity (ESEQ) for surface charging.** Model validation efforts using this ESEQ remain much needed and should be performed in the near-term.
- From a science perspective, **modeling electron flux in the energy range of a few 10's of keV remains challenging as it is closely related to substorm dynamics and associated plasma injections.** The >10 keV electron flux also varies dynamically along different orbits that are of interest to operational communities.





Charging Indices and Metrics (2/2)

- **As science understanding evolves, additional ESEQs will need to be developed and tested.** Such model validation efforts will help the improvement of modeling capabilities, advancement in science understanding, and readying our space environment models to be more useful and to be adopted by end users in the satellite operation community.
- **A long-term goal for providers of space environment data and space weather modelers is to generate the ESEQ quantities in real time operational settings** and make the data readily available to the operational community where it can be tested against on-orbit measurements of surface charging.



Surface Charging Analysis Tools

- While spacecraft charging tools have improved significantly over the past few decades, a major source of uncertainty in spacecraft charging calculations remains due to the material properties used as **input**. It is well known that material properties are not static and evolve during the journey of a spacecraft in space due to a variety of processes (contamination, oxidation, surface modifications, radiation damage, including potential feedback mechanisms among various effects). Understanding the nature of dynamical materials in space is critical to perform accurate spacecraft charging predictions as well as to mitigate potential adverse effects.
- While ongoing efforts to develop databases of material properties are notable, there is still a near-term critical need for accurate measurements of material properties, both in the lab and with experiments in space.
- Long term efforts to develop theoretical and computational models of the response of spacecraft materials to their interaction with the space environment under a variety of conditions need to be **developed and tested**. These models will eventually need to be included in spacecraft charging analysis tools to improve their predictive ability.

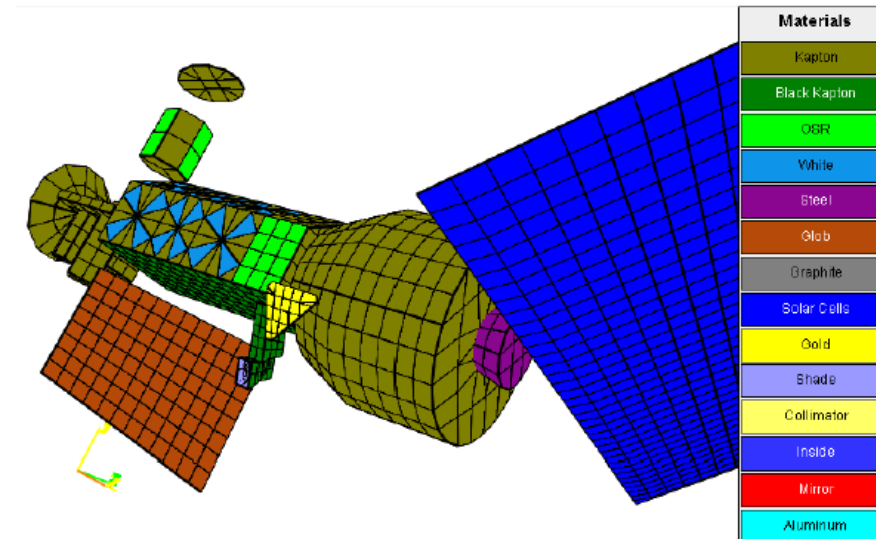
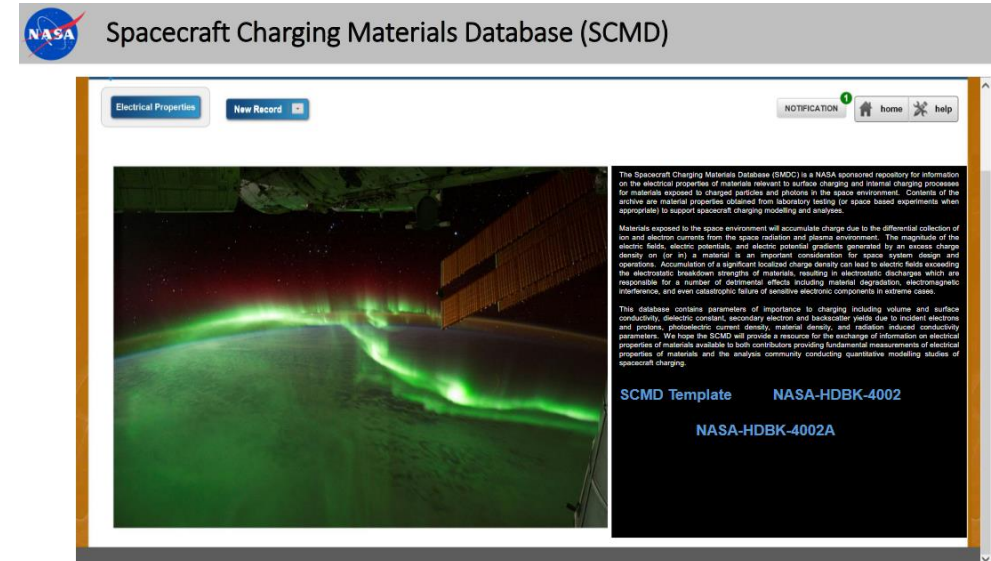
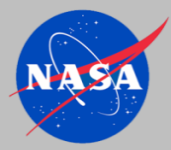


Figure 3. DMSF Spacecraft Model Constructed in *Object Toolkit*.





General Recommendations

- A prerequisite for success in mitigating spacecraft charging hazards is to establish trust across academic, government, and industry stakeholders based on improved transparency and knowledge sharing.
- Organize relevant spacecraft charging workshops and engage various communities to foster discussions among scientists, engineers, sponsors, and policymakers on these topics.
- Making publicly available satellite anomalies databases, results from space environment research studies, as well as surface charging modeling and analysis tools will promote collaborations and is highly recommended.



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Questions?