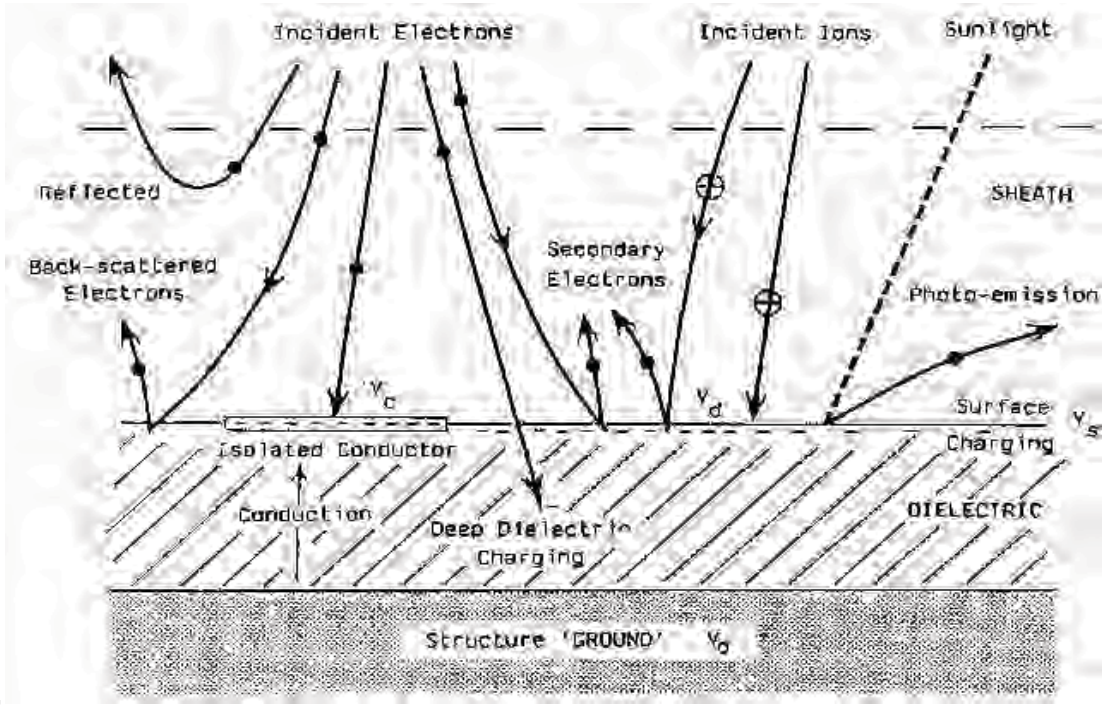
Spacecraft Charging Issues for Launch Vehicles

- **Types of charging**
  - **Surface charging**
  - **Internal (deep dielectric) charging**
- **Charging susceptibility assessment**
  - **Materials, bonding, location**
- **Immunity Evaluation**
  - **Electrostatic discharges**
    - » **Radiated broadband emissions**
    - » **Direct injection**
- **Mitigation Strategies**
  - **Material selection/design requirements**
  - **Launch constraint options**
- **Conclusions**

Launch Vehicle Charging Environments

- **Surface Charging**
  - **Low energy (1-100keV) electrons**
    - » **Charging currents up to 1nA/cm^2 at GEO**
  - **Triboelectrification from dust and ice particles in upper troposphere**
- **Internal Charging**
  - **Higher energy electrons >100keV**
  - **Up to 1pA/cm^2 charging current (GEO)**



https://www.spenvis.oma.be/help/background/charging/equipot/equipot.html

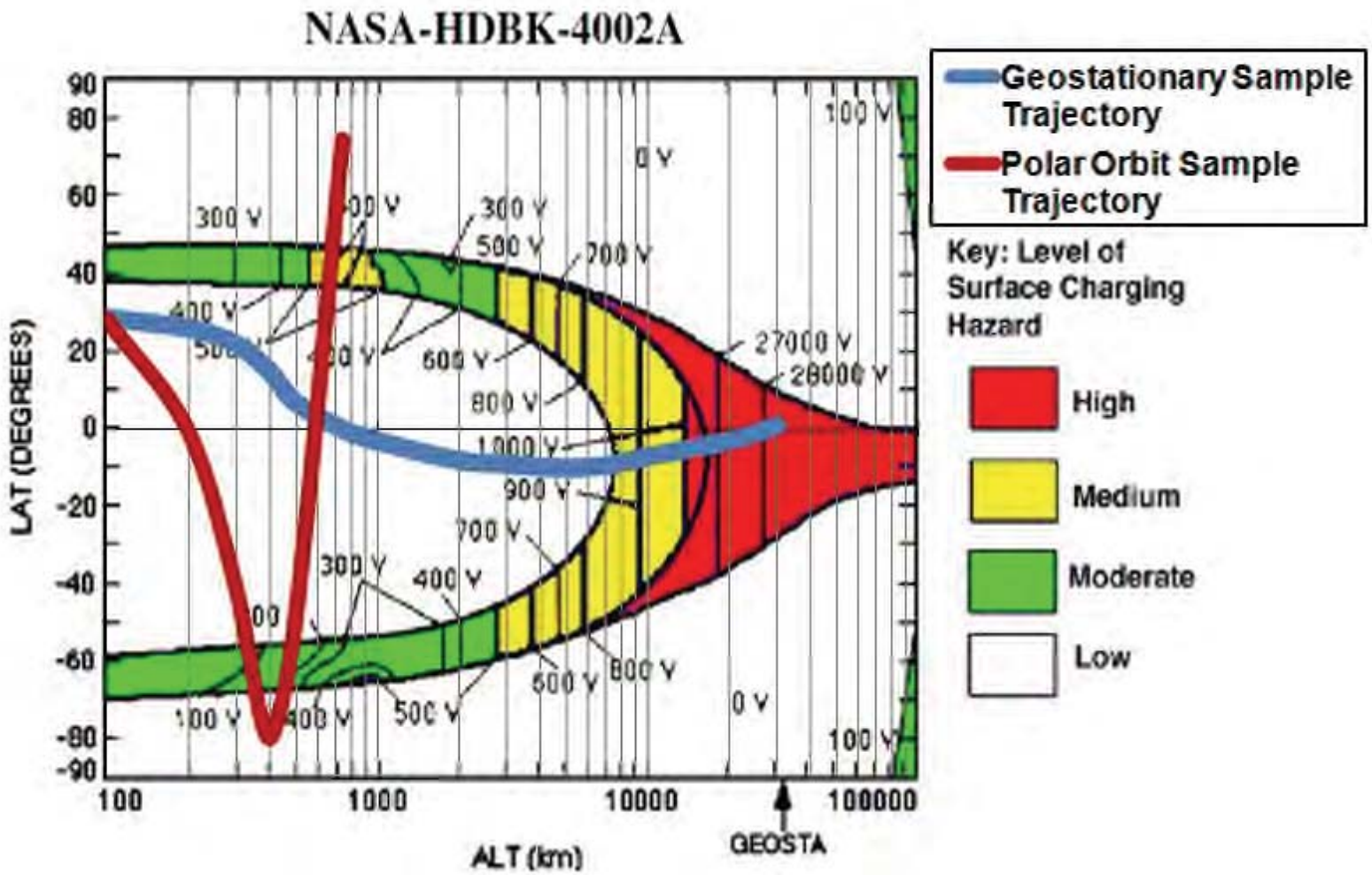
- **Primary concern from charging is electrostatic discharge effects including both direct injection and radiated emissions**
- **Internal charging is a lesser concern for LV avionics as the mission duration for the launch vehicle is typically < 8 hours**

Surface Charging Assessment

- **Bonding and resistivity requirements are checked (per NASA-STD-4003a)**
- **Often surface resistivity requirements are superseded by higher priority requirements**
  - **High dielectric materials including Kapton, Mylar, and Teflon are commonly used**
- **When violations occur, additional analyses must be performed**
- **Analyses depend on location of the violation**
  - **External to launch vehicle structure or payload fairing**
    - » **Triboelectrification and precipitation static analysis required by Range Launch Commit Criteria**
    - » **If analysis confirms possible interference, launch constraints are implemented to prevent launch during inclement weather**
  - **Other locations**
    - » **Surfaces that can be exposed to space charging effects must be assessed**
    - » **LV trajectory determines if there is a charging risk**

http://www.nasa.gov/centers/langley/images/content/396748main_Ares2.jpg

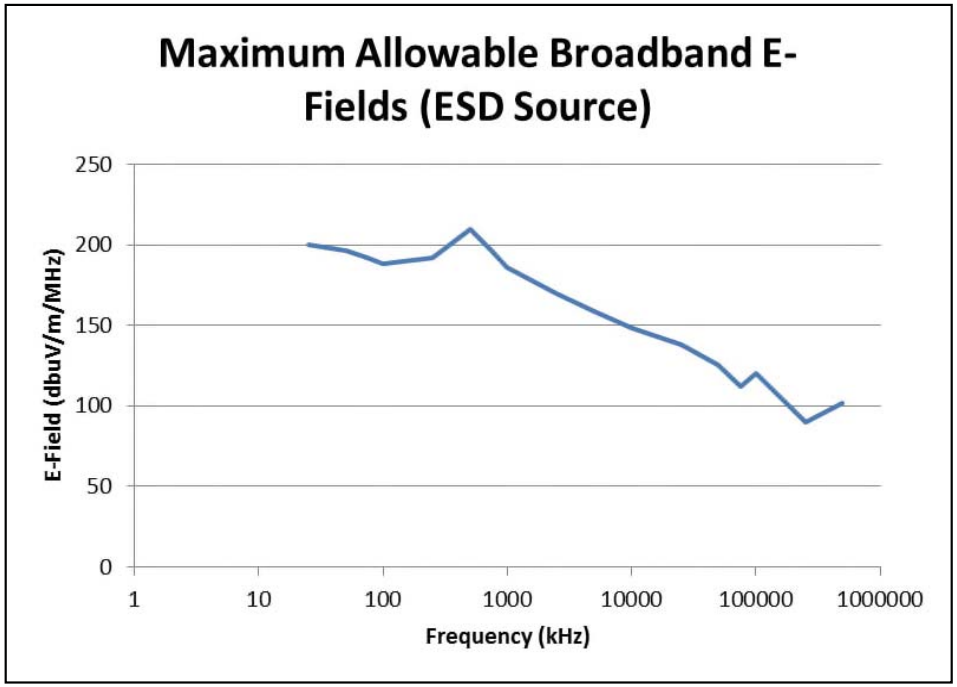
Trajectory Evaluation



- **NASA-HDBK-4002A is used for basic surface charging risk assessment**
- **When trajectory passes through charging region, ESD sensitivity must be evaluated**

ESD Source Broadband Emissions

- **Spacecraft sensitivity**
  - **Typically direct discharges to SC are not allowed**
    - » **If unavoidable, testing for immunity is required**
  - **Indirect discharges create broadband radiated emissions**
    - » **Voltages and currents can couple into and interfere with neighboring electronics and/or the spacecraft payload**
    - » **Effect on communication devices (receivers) is the most common concern**
- **Launch Vehicle sensitivity**
  - **Direct discharges may be unavoidable**
    - » **Especially to enclosures and grounded shields near the culprit materials**
  - **If LV materials are susceptible to ESD, flight critical avionics components must be tested for immunity to both broadband and direct discharges**

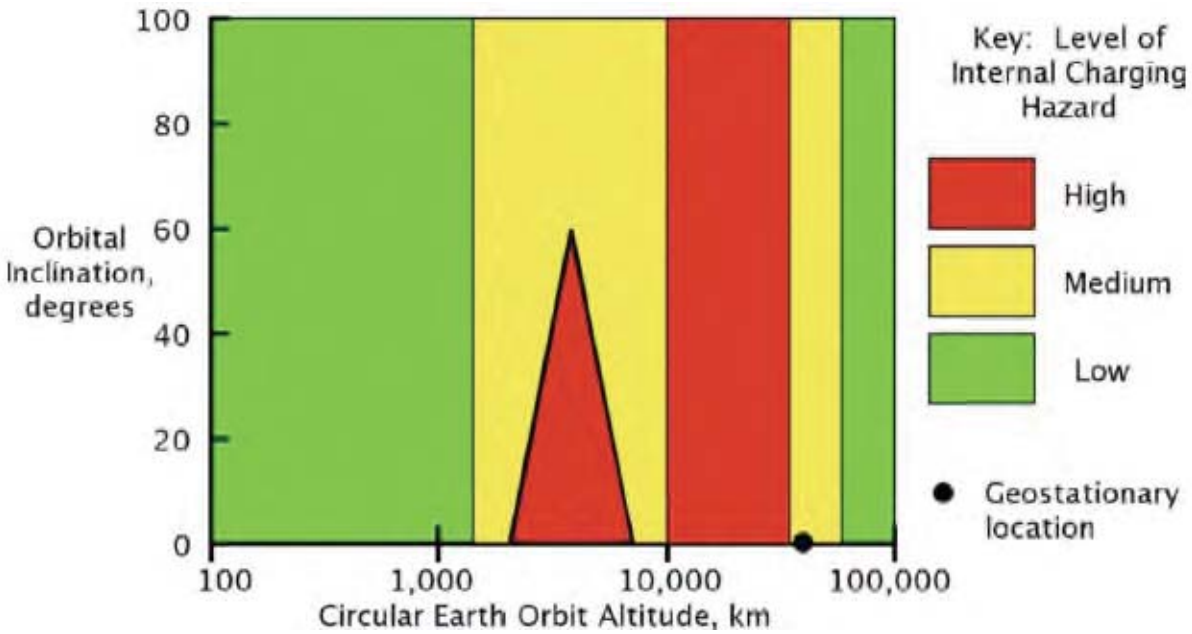


Sample broadband RF environment from EELV Specification. [3]

Internal Charging Assessment

- **Charging Environment**
  - **Higher energy electrons >100keV (Space Weather)**
  - **Electrons penetrate through enclosures and deposit directly onto circuit board**
  - **Up to 1pA/cm^2 charging current (GEO)**

- **Trajectory considerations**
  - **Polar and Geostationary trajectories**
    - » **During periods with highly elevated energetic electron flux**
  - **Multiple phasing orbits**



- **NASA-HDBK-4002A**
  - **Can be used to evaluate internal charging risk**
  - **Typically applies to SC in long term orbit**

Mitigation Strategies

- **If a spacecraft or launch vehicle susceptibility to ESD or internal charging is determined, a mitigation strategy is required to ensure mission success**
- **Mitigation options are limited:**
  - **Change in vehicle design**
    - » **Modify surfaces that are susceptible to differential charging to meet the statically dissipative resistivity requirement**
    - » **Often time and cost prohibitive if not caught early in design process**
  - **Trajectory modification**
    - » **Avoid charging region entirely prior to spacecraft separation**
    - » **Not always possible, highly dependent on spacecraft orbit requirements**
  - **Addition of Launch Constraints**
    - » **Current charging risk assessments assume worst-case environments, but an addition of a launch constraint may help to avoid these environments when there is a known threat to the spacecraft or launch vehicle**

Launch Constraints

- Use of launch constraints is a possible option for avoiding charging issues during launch operations when vehicle design requires configurations that pose a threat for charging

- Use of launch constraints for weather/space weather is common practice
  - Solar proton launch constraints to avoid exposing launch vehicle avionics to high energy solar protons and heavy ions has been used by numerous launch vehicles to protect avionics systems from single event upsets
  - Triboelectrification launch constraints are used to prevent launch through clouds types that are known to cause surface charging when a vehicle has not met surface resistivity requirements

- Spacecraft charging launch constraints in contrast has not been used very often (if at all) and represents an area very much in development

- Good design and construction practices to mitigate charging are always preferred!

Auroral Equatorward Boundary

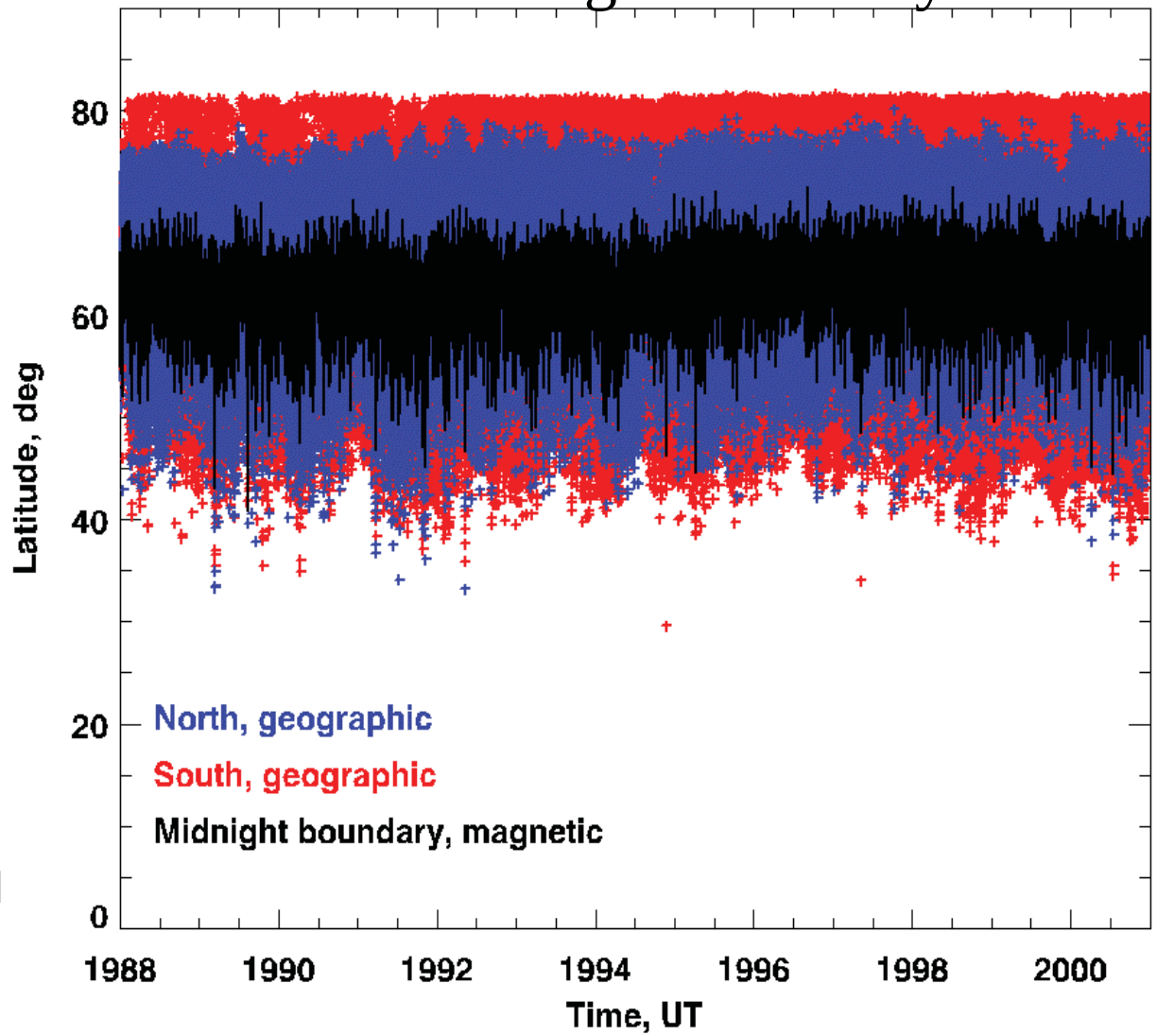
- **Auroral charging is the primary threat for short duration LEO missions**
- **Monitoring Kp index is often suggested as a method for avoiding the auroral particles**
- **Inc < ~30^0**

  low risk for auroral charging
- **~ 30^0 < inc < ~70^0**

  Kp monitoring most useful
- **Inc >~70^0**

  auroral encounters likely for all polar trajectories

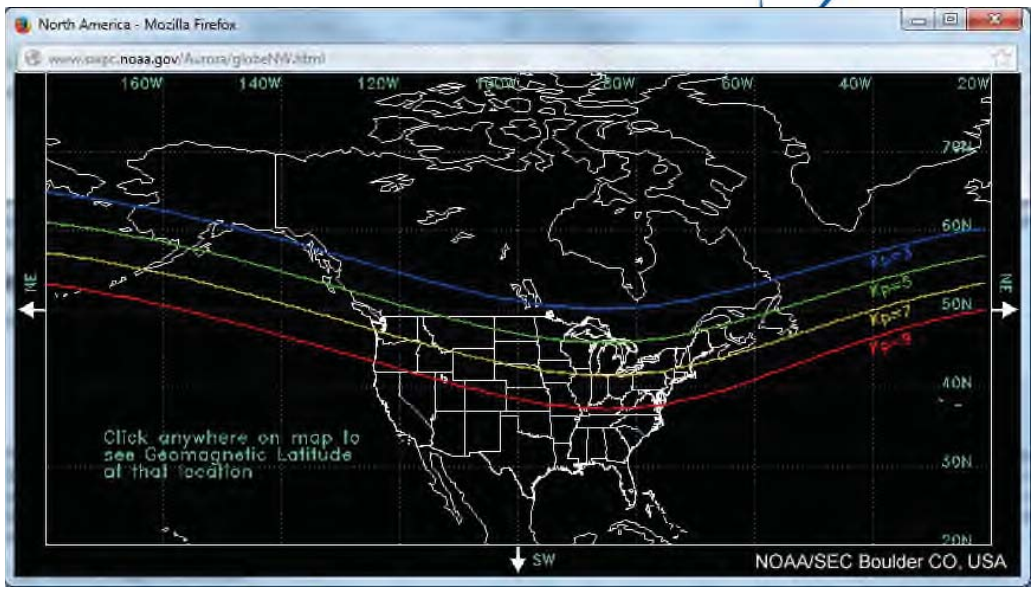
DMSP Midnight Boundary Index

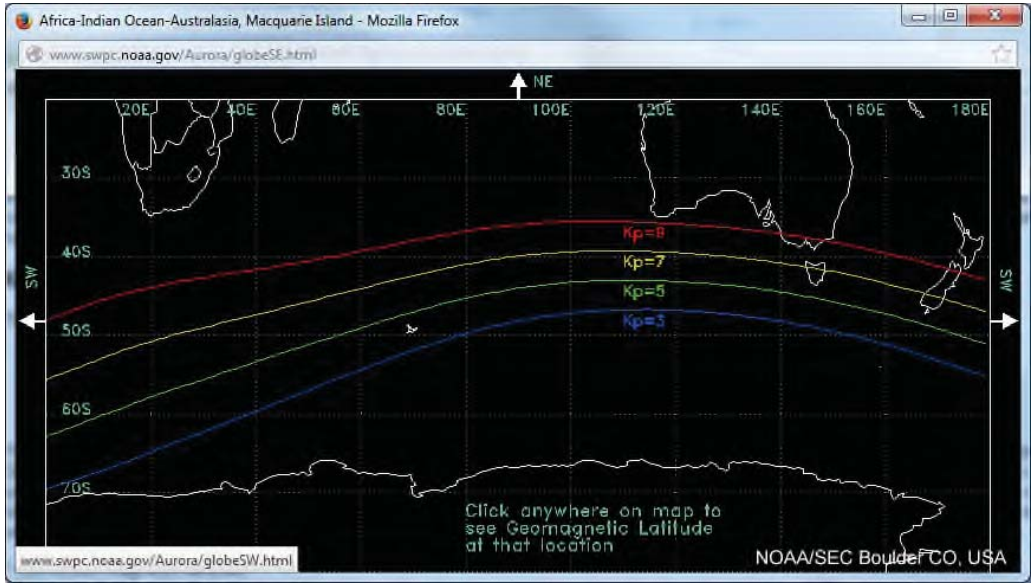


Auroral Oval Latitude

- **Latitude of aurora depends both on longitude and Kp**

- **Analysis of flight trajectory relative to auroral oval will determine if there is a potential threat and under what conditions the threat can be mitigated by Kp monitoring**

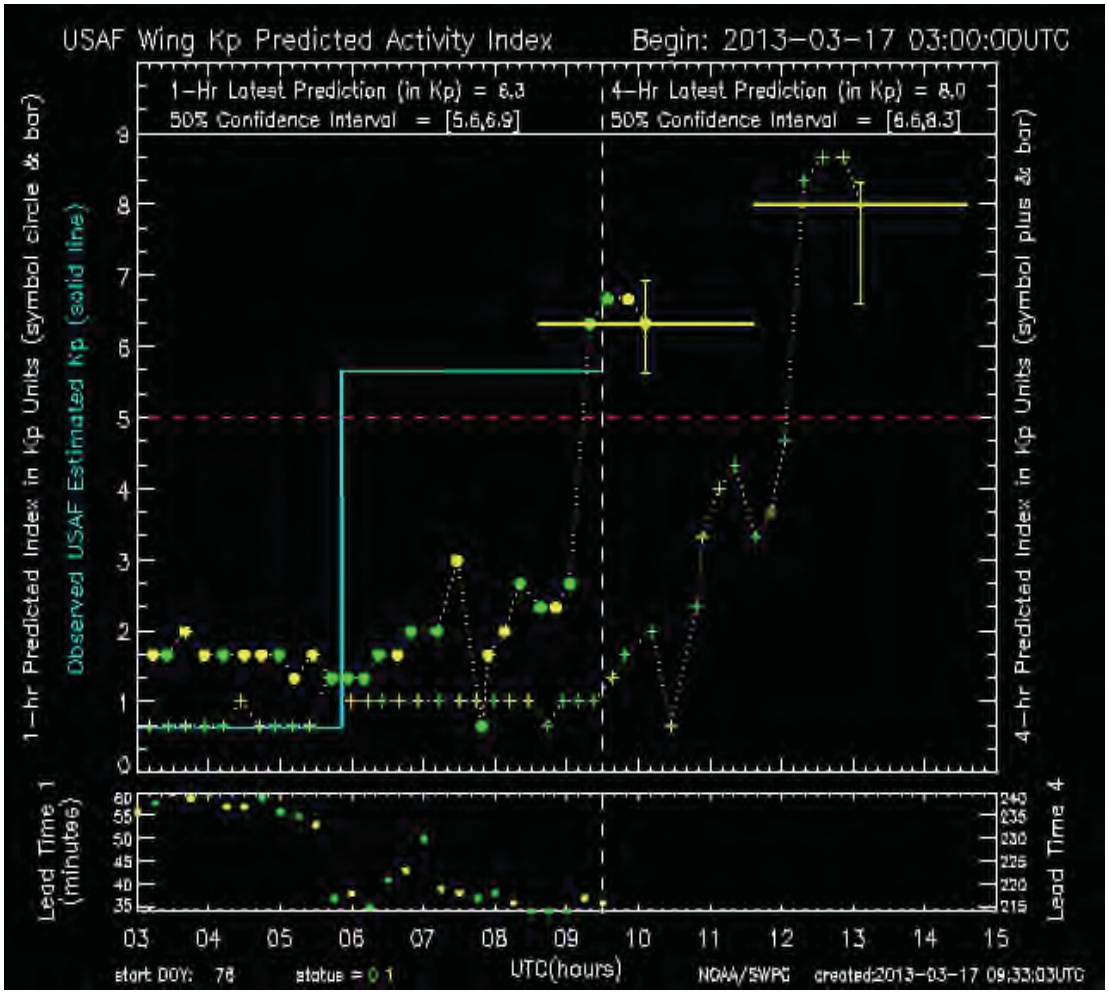




Real Time Kp Prediction Tool

- **Kp prediction tool required to avoid aurora based on Kp index**

- **One example is the USAF Wing Kp Geomagnetic Activity Index**
  - **NOAA Space Weather Prediction Center provides output from model in near real time**
  - **Based on correlation between upstream (L1) solar wind conditions and Kp index**
  - **Output updated every 15 minutes**
  - **Lead time of ~30 to 60 minutes**



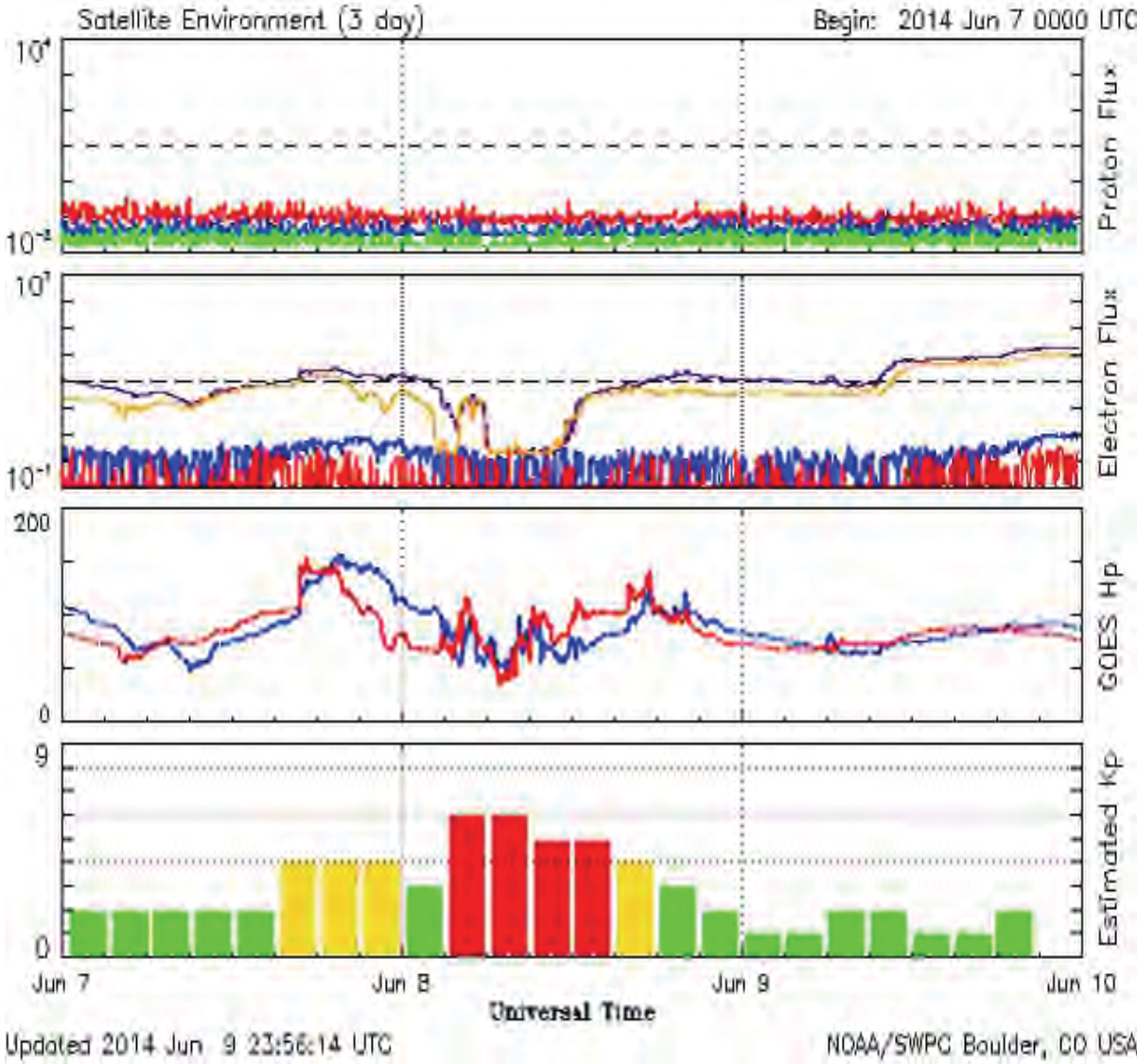
http://www.swpc.noaa.gov/wingkp/index.html

Geomagnetic Storm Monitoring

- **NOAA real time space weather products provide information useful for monitoring high latitude LEO, GTO, and GEO geomagnetic storm conditions**

- **Storm signatures suggesting charging conditions:**
  - **GEO ~MeV electron flux depletions**
  - **GEO magnetic field perturbations**

- **Use for launch constraint requires identifying threshold for parameters relevant to specific launch vehicle threat**



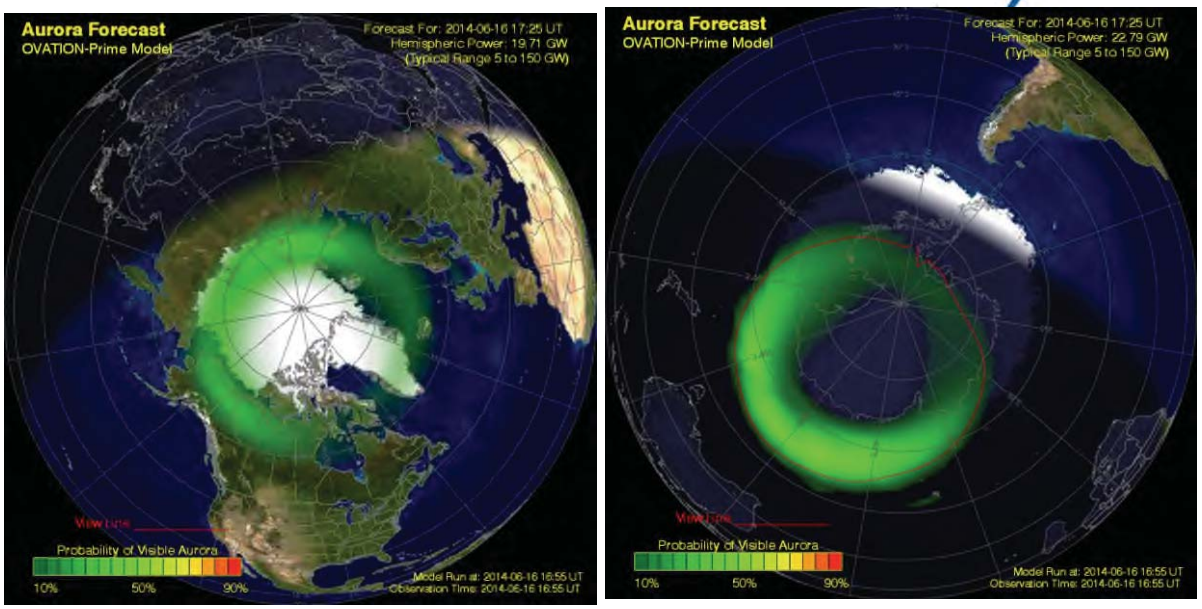
http://www.swpc.noaa.gov/rt_plots/satenv.html

Ovation Real Time Auroral Models

- **Real time aurora models are also available for use in predicting auroral boundaries**

- **NOAA Ovation Aurora**
  - **Model output is auroral energy/area color coded as relative intensity for viewing probability**
  - **Boundary provided for limit of auroral visibility**
  - **Provides conservative low latitude boundary for auroral particle flux**

- **GSFC SWRC Ovation Prime**
  - **Model output is energy flux**
  - **Updated every 10 minutes**



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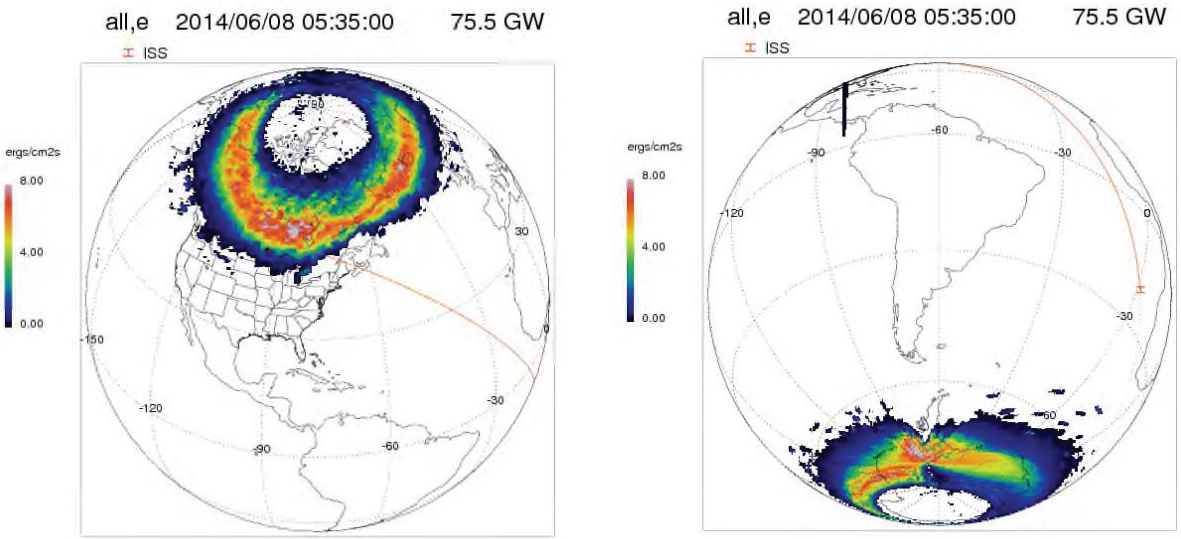

http://www.swpc.noaa.gov/ovation/

Conclusions

- **Surface charging requirements often end up in the shadow of heftier design requirements, requiring compatibility analyses be performed late in mission flow**

- **If a risk is discovered, mitigation options are limited when late in the design and mission planning process**

- **Use of launch constraints for space charging issues is a viable option that is not frequently implemented (if at all), despite being a common practice to mitigate other types of risks**

- **It is always best to get involved early in the design process to mitigate charging before it becomes an issue!**

QUESTIONS?

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