Spacecraft Charging and Auroral Boundary Predictions in Low Earth Orbit

Dr. Joseph I Minow
NASA Technical Fellow for Space Environments
Science of Space Weather Workshop
Goa, India 25-29 January 2016
joseph.minow@nasa.gov
Motivation and Outline

• Auroral charging of spacecraft is an important class of space weather impacts on technological systems in low Earth orbit
• In order for space weather models to accurately specify auroral charging environments, they must provide the appropriate plasma environment characteristics responsible for charging
• Improvements in operational space weather prediction capabilities relevant to charging must be tested against charging observations

Outline

• Spacecraft charging physics
• DMSP auroral charging
• ISS solar array and auroral charging
• Characteristics of auroral charging environments
• Space environment impacts database

Acknowledgment: DMSP SSJ data provided by NOAA National Geophysics Data Center courtesy of the US Air Force
• Auroral charging is a process of balancing currents to and from spacecraft surfaces as a function of the spacecraft potential

\[
\frac{dQ}{dt} = C \frac{dV}{dt} = \frac{d\sigma}{dt} \Delta = \sum_k I_k
\]

\[
\frac{dQ}{dt} = \sum_k I_k = 
\begin{align*}
+ I_i (V) & \quad \text{incident ions} \\
- I_e (V) & \quad \text{incident electrons} \\
+ I_{bs,e} (V) & \quad \text{backscattered electrons} \\
\pm I_c (V) & \quad \text{conduction currents} \\
+ I_{se} (V) & \quad \text{secondary electrons due to } I_e \\
+ I_{si} (V) & \quad \text{secondary electrons due to } I_i \\
+ I_{ph,e} (V) & \quad \text{photoelectrons}
\end{align*}
\]

(Garrett and Minow, 2004)
DMSP Charging

US Air Force
• Low energy ($E_0 \sim 0$) background ions accelerated by the spacecraft potential show up as sharp “line” of high ion flux in single channel

$$E = E_0 + q\Phi$$

• Assume initial energy $E_0 = 0$ with singly charge ions ($O^+, H^+$) and read potential (volts) directly from ion line energy (eV)

• DMSP SSJ4, SSJ5 detectors
  – Electrons: 20 channels
    30 eV to 30 keV
  – Ions: 20 channels
    30 eV to 30 keV
  – Nominal channel energies used for this work
Auroral Charging Conditions

Necessary conditions for high-level (≥100 V) auroral charging*

- No sunlight (or ionosphere below spacecraft in darkness)
- Intense electron flux >10^8 e/cm^2·s·sr at energies of 10’s keV
- Low ambient plasma density (<10^4 #/cm^3)

Energy Flux

DMSP F16/SSJ 2012/07/16

Energy flux threshold >60 mW/m²

Electrons

Ions

Energy (keV)

Log₁₀ Energy (erg)

Lₐ (deg)

Lon (deg)

Hour (UTC)
Individual Spectra

(a) 19:34:21 UTC
- 19.572750 UTC
- 19:34:21 UTC
- Spectra ave: 1
- idx: 70462 70462

(b) 19:35:42 UTC
- 19.595150 UTC
- 19:35:42 UTC
- Spectra ave: 1
- idx: 70543 70543

Graphs showing energy spectra with logarithmic y-axis and linear x-axis.
### Ambient background
- \( n = 1.0 \times 10^{10} \) \(1/\text{m}^3\)
- \( T_e = 0.2 \) \(\text{eV}\)

### Maxwellian
- \( J_{\text{max}} = 4.0 \times 10^{-6} \) \(\text{A/m}^2\)
- \( T_e = 3.0 \times 10^3 \) \(\text{eV}\)

### Gaussian (beam)
- \( J_{\text{gau}} = 0.9 \times 10^{-4} \) \(\text{A/m}^2\)
- \( E_{\text{gau}} = 10.0 \times 10^3 \) \(\text{eV}\) beam energy
- \( d_{\text{gau}} = 4.0 \times 10^3 \) \(\text{eV}\) beam width

### Power Law
- \( J_{\text{pwr}} = 3.0 \times 10^{-7} \) \(\text{A/m}^2\)
- \( \alpha = 1.15 \) exponent
- \( E_1 = 50.0 \) \(\text{eV}\), first energy
- \( E_2 = 1.0 \times 10^5 \) \(\text{eV}\), second energy

\[
\text{Flux} (E) = \sqrt{\frac{e}{2\pi m_e \theta}} E \exp \left( -\frac{E}{\theta} \right) + \pi \xi_{\text{max}} E \exp \left( -\frac{E}{\theta_{\text{max}}} \right) + \pi \xi_{\text{gau}} E \exp \left( -\frac{(E_{\text{gau}} - E)^2}{\Delta} \right) + \pi \xi_{\text{pwr}} E^{-\alpha}
\]

[Davis et al., 2011]
Inverted V, Broadband Aurora
Secondary Electron Yields

Charging is suppressed when \( \text{SEY} > 1 \)

\[
\frac{dQ}{dt} = \sum_k I_k = +I_i - I_e + I_{se} + I_{ph,e}
= +I_i - I_e (1 - \delta) + I_{ph,e}
\]

\[\delta_{\text{m}}, E_{\text{m}} \text{ from Hasting and Garrett, 1996}\]

\[\delta_e(E, \theta) = \delta_{e,\text{max}} \frac{E}{E_{\text{max}}} \exp(2 - 2 \sqrt{\frac{E}{E_{\text{max}}}}) \exp[2(1 - \cos \theta)]\]

**Sternglass, 1954**

**Katz et al., 1977; Whipple, 1981**

\[\delta_e(E, \theta) = \frac{1.114\delta_{e,\text{max}}}{\cos \theta} \left[ \frac{E}{E_{\text{max}}} \right]^{0.35} \left\{ 1 - \exp \left[ -2.28\cos \theta \left[ \frac{E_{\text{max}}}{E} \right]^{1.35} \right] \right\}\]
ISS Charging
Potential variations due to (a) $vxB.L$ (b) eclipse exit solar array (c) auroral charging
26 March 2008 -- Auroral Charging

~17 volts

26 Mar 2008 07:30 – 08:00 UT

[adapted from Craven et al., 2009]
9 March 2012

ISS crew imagery

$\Phi_{s/c}$

$N_e$

$T_e$

Lat/Lon

mlat
9 March 2012

ISS crew imagery
iSWA Ovation Prime, ISS Charging
Aurora Models

- NASA CCMC implementation of Ovation Prime is a good example of an auroral model providing total energy flux.
- Total ions, electrons, and ions+electrons energy flux to $8 \text{ erg/cm}^2\cdot\text{s} \ (= \text{mW/m}^2)$.
Aurora Models

- NASA CCMC implementation of Ovation Prime is a good example of an auroral model providing total energy flux
- Total ions, electrons, and ions+electrons energy flux to 8 erg/cm$^2$-s (=mW/m$^2$)
- Increase the energy flux coverage to include 10’s to 100’s ergs/cm$^2$-s to consider auroral charging regime
- Energy flux for $J_E$ (≥10 keV) erg/cm$^2$-s
Space Weather Database Of Notifications, Knowledge, Information (DONKI)

CCMC DONKI

http://kauai.ccmc.gsfc.nasa.gov/DONKI/
Space Weather Database Of Notifications, Knowledge, Information (DONKI)

Go to:
- DONKI Home
- DONKI Documentation
- Search Space Weather Activity
- Search Notification Archive
- Space Environment Effects and Anomalies
- Logoff
- Edit Personal Profile
- Change Password

Space Environment Effect and Anomalies Archive

Click on the link below to generate/search reports in the archive.

- Report Space Environment Effect
- Report Spacecraft Anomaly
- Search Archive

Important Disclaimer Notice

If you are looking for the official U.S. Government forecast for space weather, please go to NOAA’s Space Weather Prediction Center (http://swpc.noaa.gov). This "Experimental Research Information" consists of preliminary NASA research products and should be interpreted and used accordingly.

NASA Official: Maria Kuznetsova
<table>
<thead>
<tr>
<th>Activity ID</th>
<th>Project Name</th>
<th>System</th>
<th>Effect Time in UT</th>
<th>Orbit Type</th>
<th>Effect Type</th>
<th>Effect Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-02-27T03:24:00-CHANDRA-RAD-001</td>
<td>CHANDRA</td>
<td>instrument</td>
<td>2012-02-27T03:24:00Z</td>
<td>Elliptical</td>
<td>radiation event</td>
<td>2012/058: Chandra X-Ray Observatory (CXO) Advanced CCD Imaging Spectrometer (ACIS) instrument radiation intervention. Science observations interrupted 27 Feb at 03:24 UTC to 27 Feb 20:23 UTC (16.9 hours) by a manual event due to ACE P3 (soft) particle signature.</td>
</tr>
<tr>
<td>2012-03-07T05:30:00-CHANDRA-RAD-001</td>
<td>CHANDRA</td>
<td>instrument</td>
<td>2012-03-07T05:30:00Z</td>
<td>Elliptical</td>
<td>radiation event</td>
<td>2012/067: Chandra X-Ray Observatory (CXO) Advanced CCD Imaging Spectrometer (ACIS) instrument radiation intervention. Science observations interrupted 7 Mar at 05:30 UTC to 13 Mar 05:14 UTC (122.2 hours) by an auto event due to HRC (hard) particle signature.</td>
</tr>
<tr>
<td>2012-03-09T12:00:00-ISS-CHRG-001</td>
<td>ISS</td>
<td>vehicle</td>
<td>2012-03-09T12:00:00Z</td>
<td>Inclined</td>
<td>spacecraft charging</td>
<td>2012/069: ISS auroral frame charging observed at high southern latitudes in period 12:00 UTC to 16:30 UTC. Maximum frame potentials -6 to 14 V. Kp=5.7 to 6.7 at times of significant charging. Charging levels from ISS Floating Potential Measurement Unit.</td>
</tr>
<tr>
<td>2012-03-10T10:00:00-ISS-CHRG-001</td>
<td>ISS</td>
<td>vehicle</td>
<td>2012-03-10T10:00:00Z</td>
<td>Inclined</td>
<td>spacecraft charging</td>
<td>2012/070: Possible ISS auroral frame charging at high southern latitudes in period 10:00 UTC to 14:00 UTC. Maximum frame potentials ~1 to 2 V. Kp=2.0 to 2.7 at times of significant charging. Charging levels from ISS Floating Potential Measurement Unit. (Note: Additional verification required due to low Kp.)</td>
</tr>
<tr>
<td>2012-05-17T02:18:00-CHANDRA-RAD-001</td>
<td>CHANDRA</td>
<td>instrument</td>
<td>2012-05-17T02:18:00Z</td>
<td>Elliptical</td>
<td>radiation event</td>
<td>2012/138: Chandra X-Ray Observatory (CXO) Advanced CCD Imaging Spectrometer (ACIS) instrument radiation intervention. Science observations interrupted 17 May at 02:18 UTC to 18 May 04:52 UTC (26.1 hours) by an auto event due to E1300 (hard) particle signature.</td>
</tr>
<tr>
<td>2012-07-12T19:59:00-CHANDRA-RAD-001</td>
<td>CHANDRA</td>
<td>instrument</td>
<td>2012-07-12T19:59:00Z</td>
<td>Elliptical</td>
<td>radiation event</td>
<td>2012/194: Chandra X-Ray Observatory (CXO) Advanced CCD Imaging Spectrometer (ACIS) instrument radiation intervention. Science observations interrupted 12 Jul at 19:59 UTC to 14 Jul 00:09 UTC (17.1 hours) by an auto event due to E1300 (hard) particle signature.</td>
</tr>
<tr>
<td>2012-07-14T21:08:00-CHANDRA-RAD-001</td>
<td>CHANDRA</td>
<td>instrument</td>
<td>2012-07-14T21:08:00Z</td>
<td>Elliptical</td>
<td>radiation event</td>
<td>2012/196: Chandra X-Ray Observatory (CXO) Advanced CCD Imaging Spectrometer (ACIS) instrument radiation intervention. Science observations interrupted 14 Jul at 21:08 UTC to 16 Jul 05:16 UTC (22.3 hours) by an auto event due to E1300 (hard) particle signature.</td>
</tr>
</tbody>
</table>
Space Environment Effect Report

Activity ID: 2012-03-09T12:00:00-ISS-CHRG-001
Project/Spacecraft Name: International Space Station
System: vehicle
Orbit Type: Inclined
Effect Time (UTC): 2012-03-09T12:00:00Z
Effect Time (MLT):
Effect Type: spacecraft charging
Location Info: LON=None Entered LAT=None Entered ALT=None Entered (undefined)
Effect Duration: None Entered
Effect Magnitude: undefined
Allow Public Access: false

Description:
2012/069: ISS auroral frame charging observed at high southern latitudes in period 12:00 UTC to 16:30 UTC. Maximum frame potentials ~6 to 14 V. Kp=5.7 to 6.7 at times of significant charging. Charging levels from ISS Floating Potential Measurement Unit.

Image file: FPMU summary data

Submitted on 2014-09-30T19:42Z by Joseph Minow

Edit This SE Effect Report
Add Related Space Weather Activity

All directly linked activities:
- 2012-03-09T03:00:00-GST-001
- NOAA Kp: 7 (2012-03-09T06:00Z) DELETE
- NOAA Kp: 6 (2012-03-09T12:00Z)

Post a Comment: