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
Surface Charging Physics

- Auroral charging is a process of balancing currents to and from spacecraft surfaces as a function of the spacecraft potential

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

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

(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)

DMSP F16: -1000 V Charging Event

DMSP F16/SSJ 2012/07/16

J(>30 eV), J(>2 keV), J(>9.4 keV), J(>15.6 keV)

log₁₀ Energy (keV)

Electrons

Log₁₀ #/cm² sec sr keV

Lon (deg)

Lat (deg)

Hour (UTC)

NASA/MSFC
Energy Flux

Energy flux threshold
>60 mW/m²
Individual Spectra

DMSP F16/SSJ 2012/07/16

nA/cm²

10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵

log₁₀ Energy (keV)

10⁻²
10⁻¹
10
10³
10⁴

Electrons

Ions

19:33:00 19:34:00 19:35:00 19:36:00 19:37:00 19:38:00 19:39:00 19:40:00

Hour (UTC)

Lat (deg)

0 50 -50

Lon (deg)

300 200 100 0

(a) (b)

NASA/MSFC
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
**Fontheim Distribution**

**Ambient background**

\[ n = 1.0 \times 10^{10} \text{ } 1/m^3 \]
\[ T_e = 0.2 \text{ } eV \]

**Maxwellian**

\[ J_{max} = 4.0 \times 10^{-6} \text{ } A/m^2 \]
\[ T_e = 3.0 \times 10^3 \text{ } eV \]

**Gaussian (beam)**

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

**Power Law**

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

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

[Davis et al., 2011]
Secondary Electron Yields

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

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

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

NASA
Potential variations due to (a) vxB.L  (b) eclipse exit solar array (c) auroral charging
26 March 2008 -- Auroral Charging

ISS/FPMU 2008/03/26 (2008/086)

~17 volts

26 Mar 2008 07:30 – 08:00 UT

JHU/APL

Normalized B2i = 0.2  Flux = 728 MWb
Equivalent Kp = 3.0  Global e- E-Flux = 23.0 MW

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

ISS crew imagery

$\Phi_{s/c}$

$N_e$

$T_e$

Lat/Lon

mlat
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 erg/cm²-s (=mW/m²).
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 \(J_E(\geq 10 \text{ keV})\) erg/cm\(^2\)-s
Space Weather Database Of Notifications, Knowledge, Information (DONKI)

Space Weather Database Of Notification, Knowledge, Information (DONKI) (developed at the Community Coordinated Modeling Center, CCMC) is a comprehensive on-line tool for space weather forecasters, scientists, and the general space weather community.

DONKI provides:
- Chronicles the daily interpretations of space weather observations, analysis, models, forecasts, and notifications provided by the Space Weather Research Center (SWRC).
- Comprehensive knowledge-base search functionality to support anomaly resolution and space science research.
- Intelligent linkages, relationships, cause-and-effects between space weather activities.

DONKI Goals:
- One-stop on-line tool for space weather forecasters.
- Gathers and organizes space weather scientists interpretations and daily activities with correlations and direct links between relevant space weather observations.
- Enables remote participation by students, world-wide partners, model and forecasting technique developers.

Using DONKI (see menu on the left):
- Anyone can search/view data already stored on DONKI.
- Registered Users can make comments on any SW Activity.
- Power Users can enter data into DONKI (Click here to request power user privileges).

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 Kueppersova

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=6.7 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 Rp.)</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>
</tbody>
</table>
| 2012-07-14T21:08:00-CHANDRA-RAD-001 | CHANDRA      | instrument | 2012-07-14T21:08:00Z | Elliptical | radiation event | 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
Space Environment Effect Report

Activity ID: 2012-03-09T12:00:00-00-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:

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

Post a Comment:
Space Environment Effect Report
Questions?