Spacecraft Charging and Auroral Boundary Predictions in Low Earth Orbit

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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

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

$$\frac{dQ}{dt} = \sum_k I_k =$$

$+ I_i(V)$ **incident ions**

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

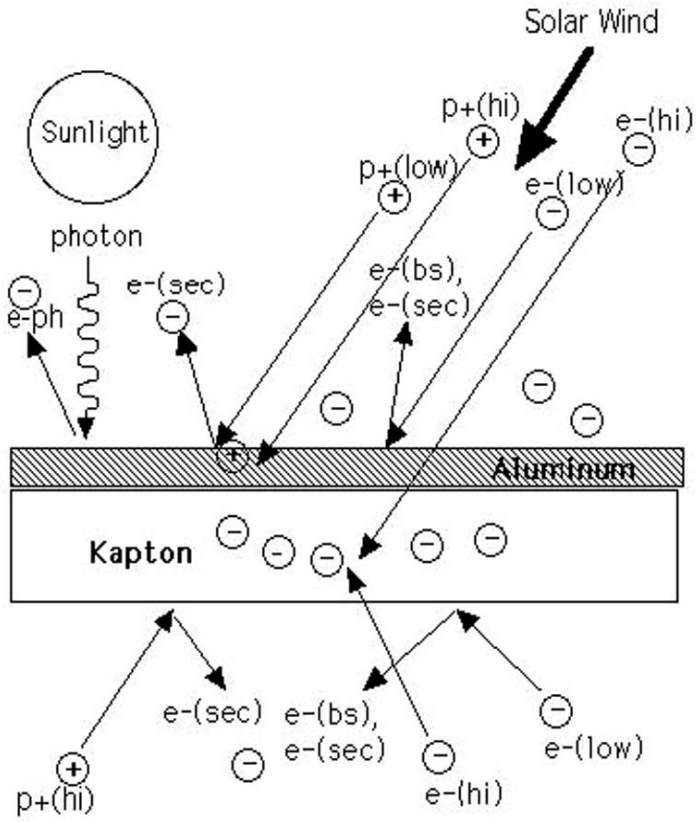
$+ I_{bs,e}(V)$ **backscattered electrons**

$\pm I_c(V)$ **conduction currents**

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

$+ I_{si}(V)$ **secondary electrons due to I_i**

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



(Garrett and Minow, 2004)

DMSP Charging

DMSP Auroral Charging

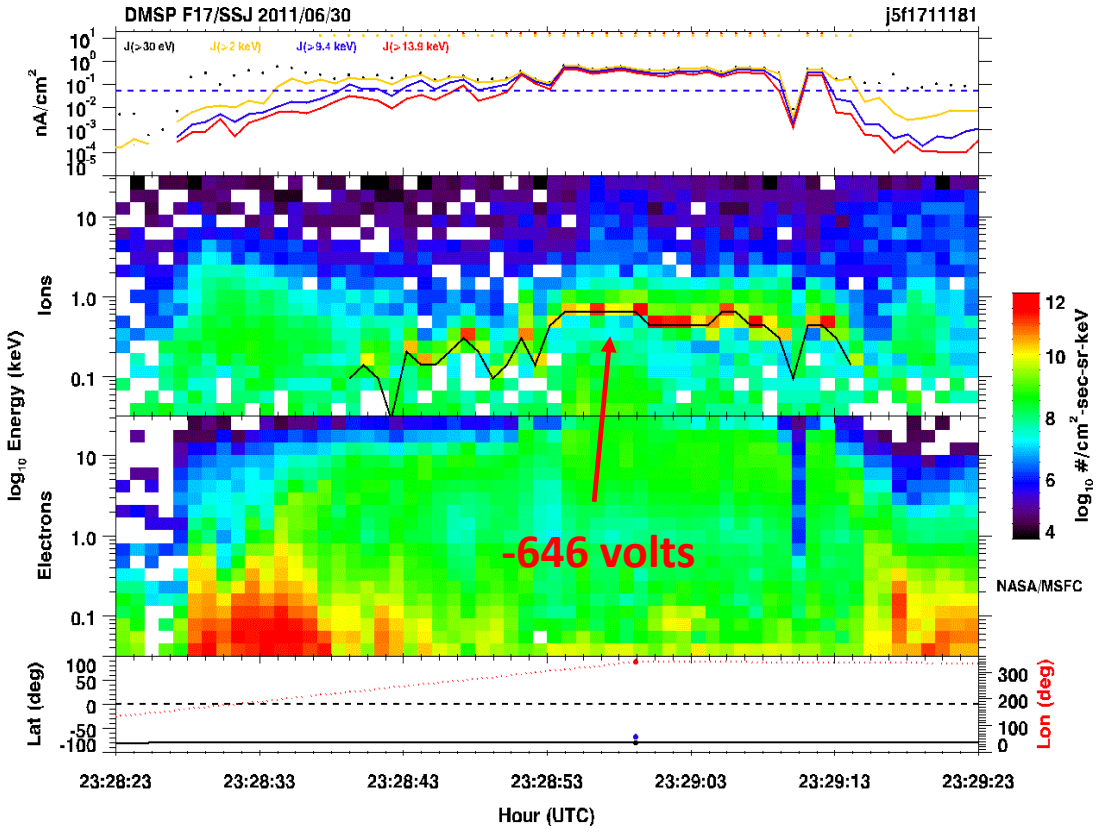
- Low energy (E_0 ~ 0) background ions accelerated by the spacecraft potential show up as sharp "line" of high ion flux in single channel

$$E = E_0 + q\Phi$$

- 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

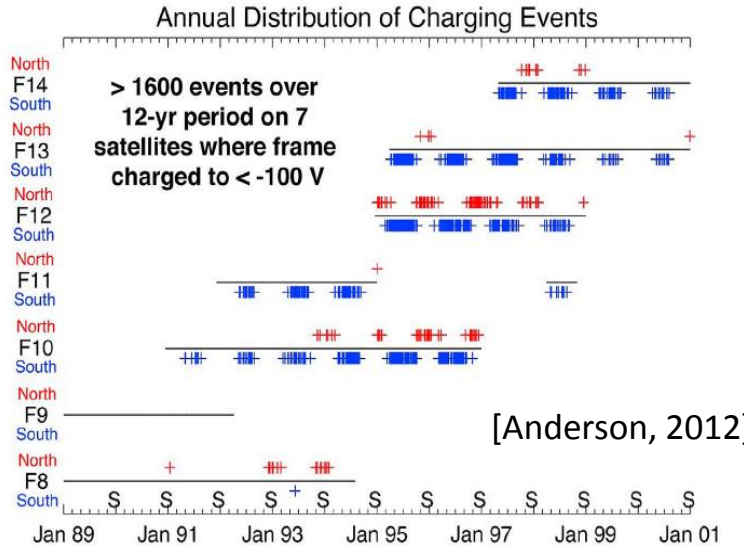
"Ion Line" Charging Signature



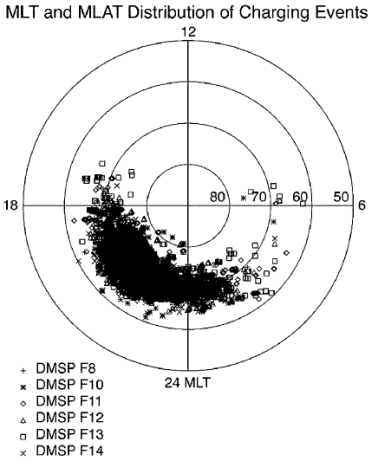
Auroral Charging Conditions

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

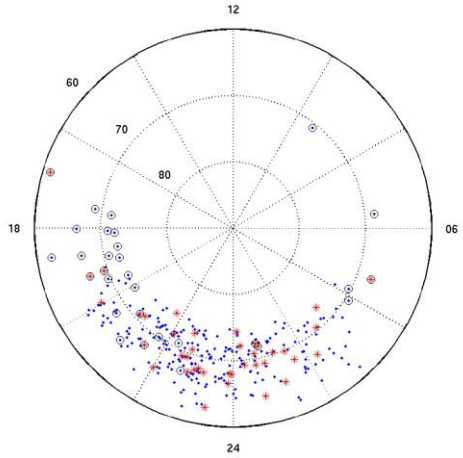
- No sunlight (or ionosphere below spacecraft in darkness)
- Intense electron flux >10^8 e/cm^2-s-sr at energies of 10's keV
- Low ambient plasma density (<10^4 #/cm^3)



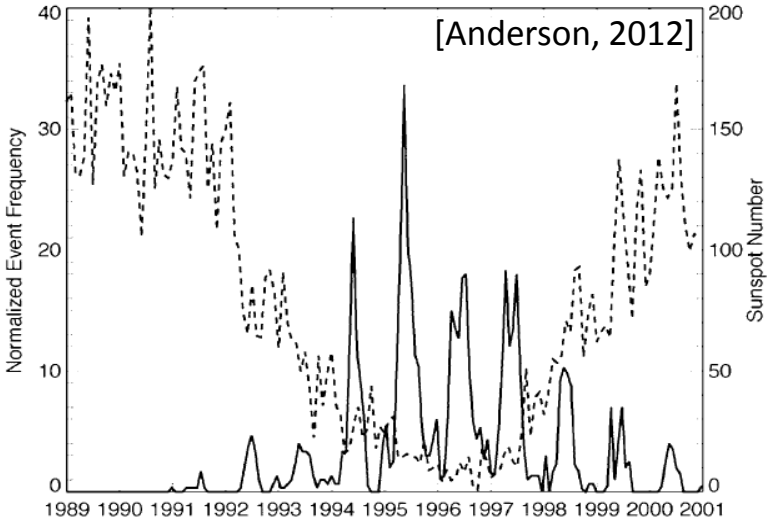
[Anderson, 2012]



[Anderson, 2012]

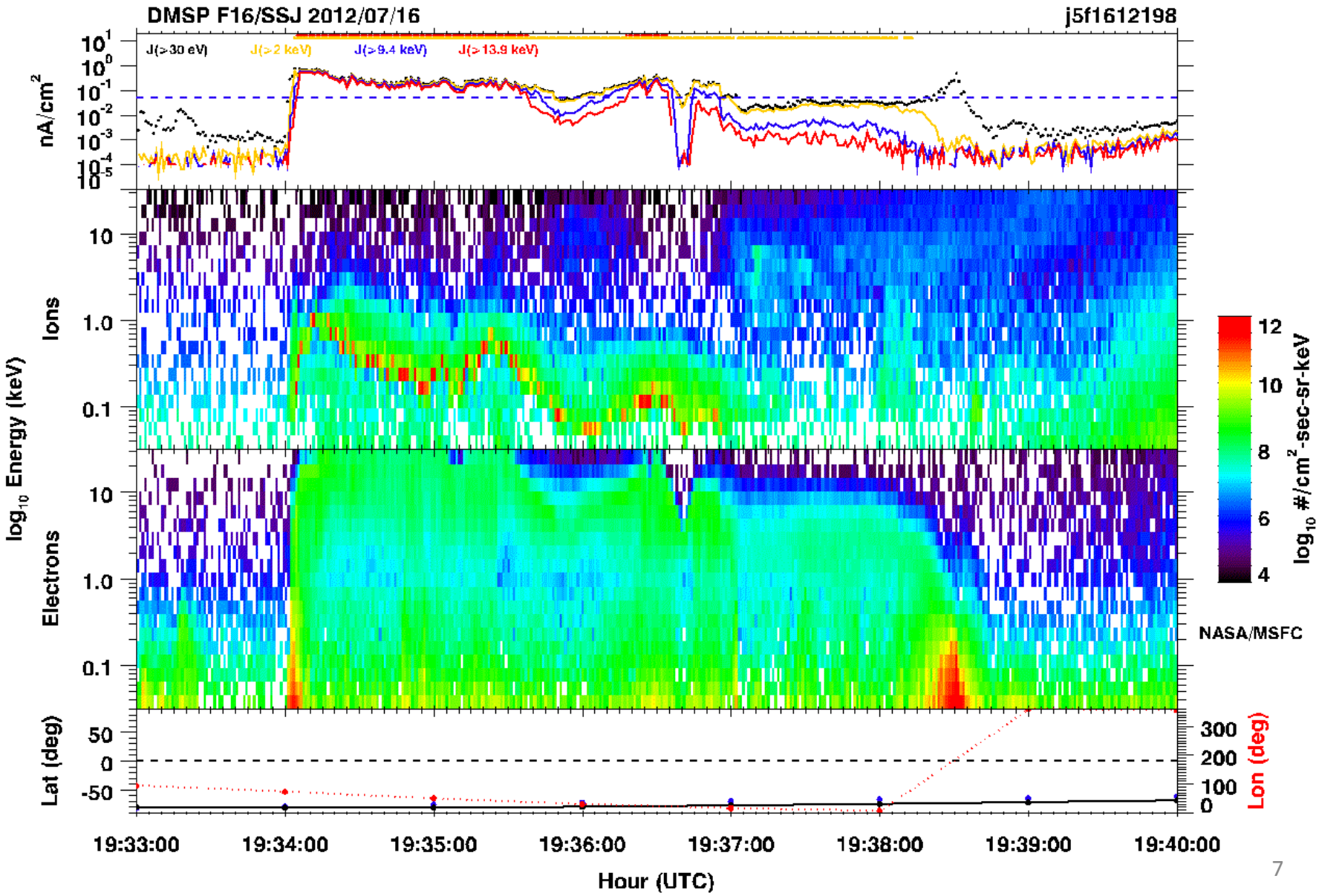


[Eriksson and Wahlund, 2006]



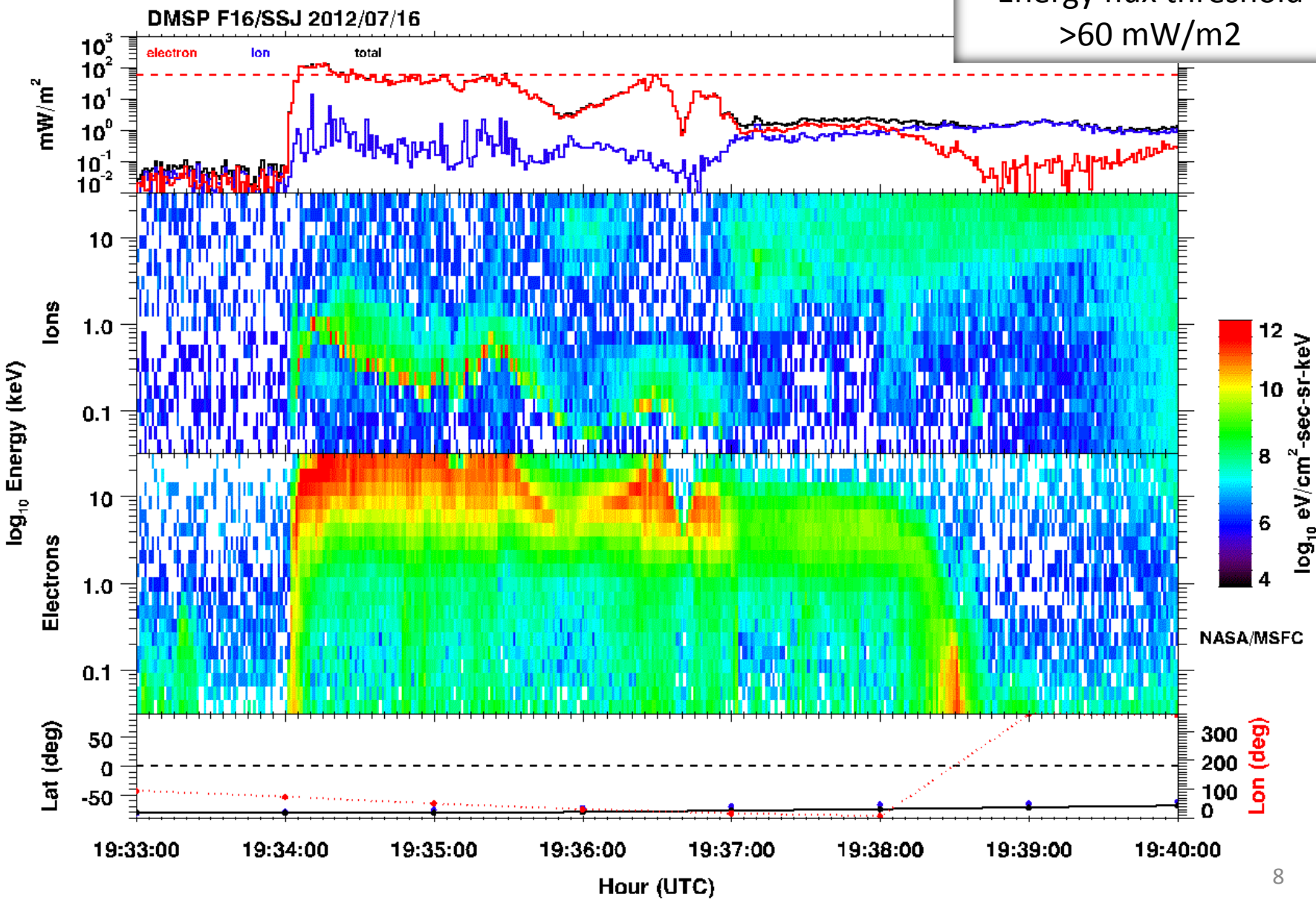
*Gussenhoven et al., 1985; Frooninckx and Sojka, 1992; Eriksson and Wahlund, 2006.

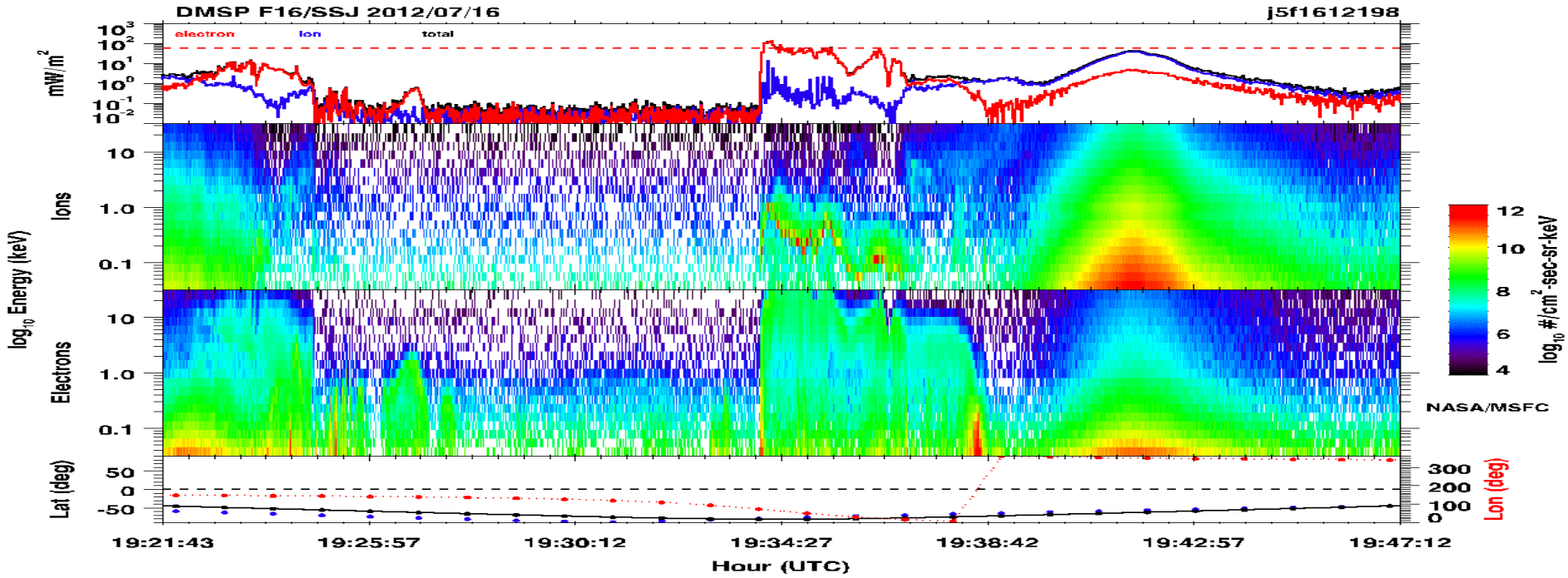
DMSP F16: -1000 V Charging Event

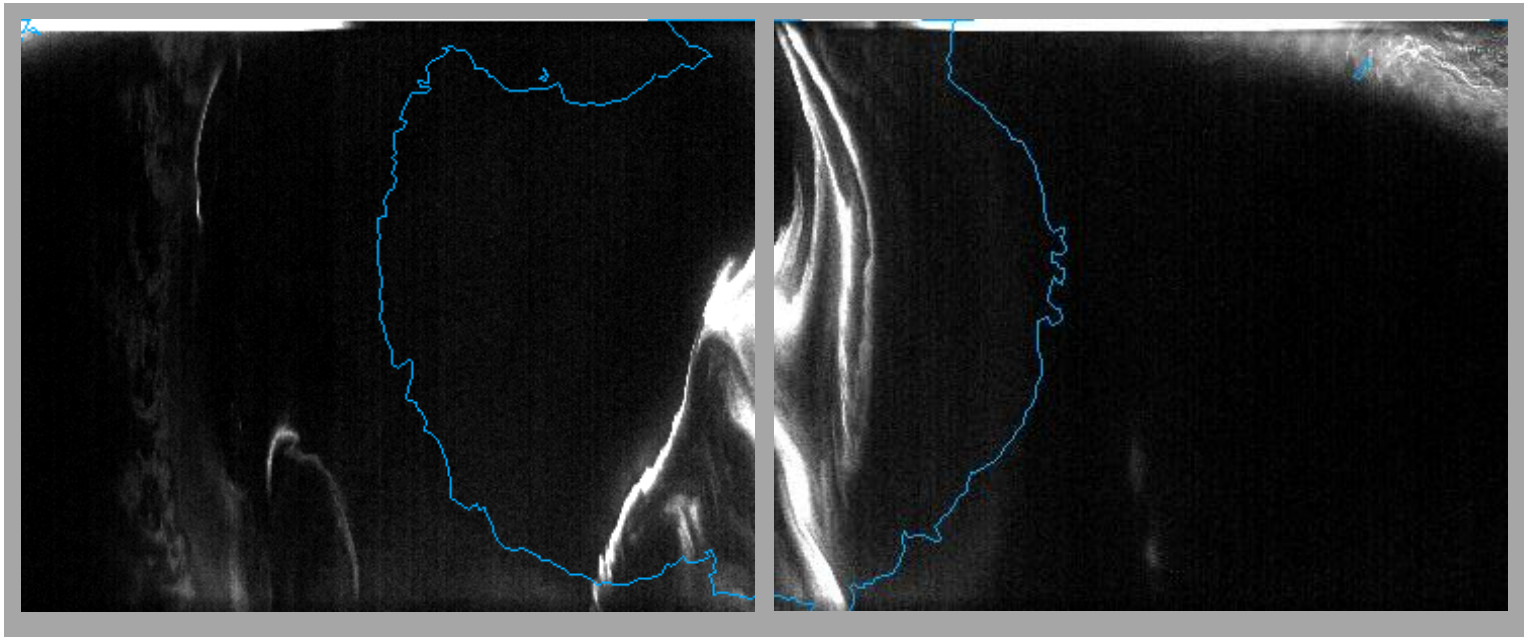


Energy Flux

Energy flux threshold
>60 mW/m2







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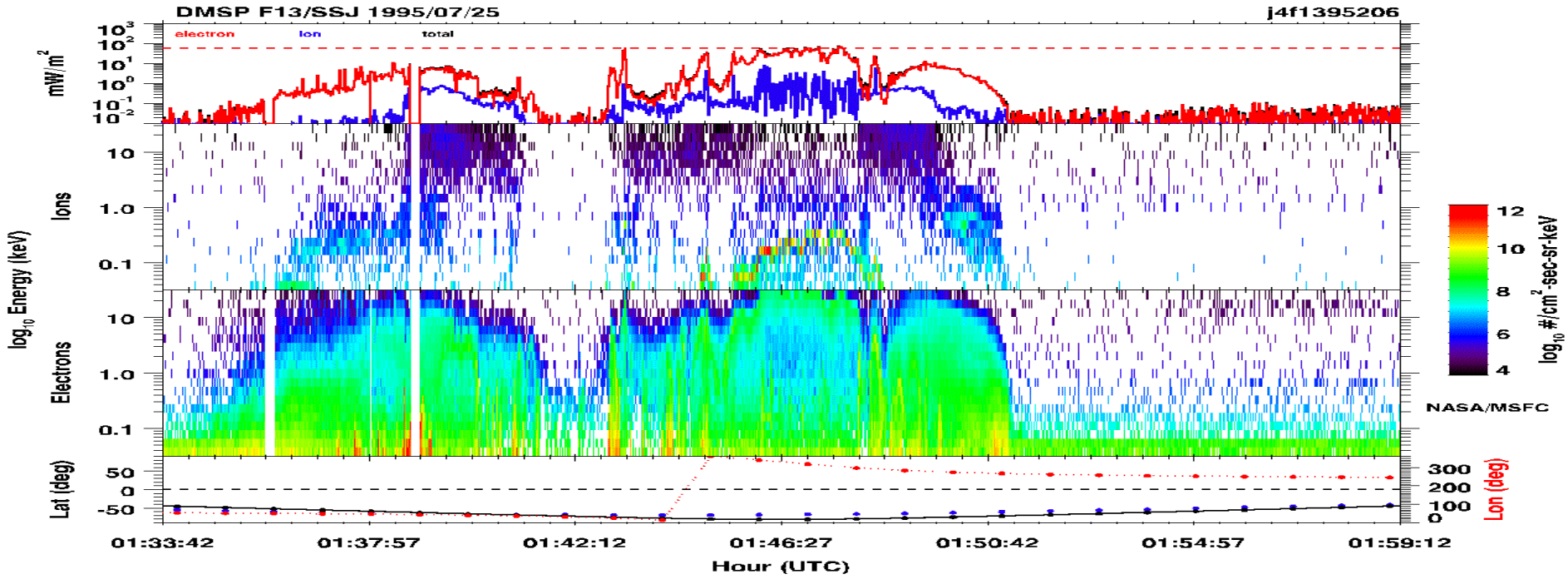
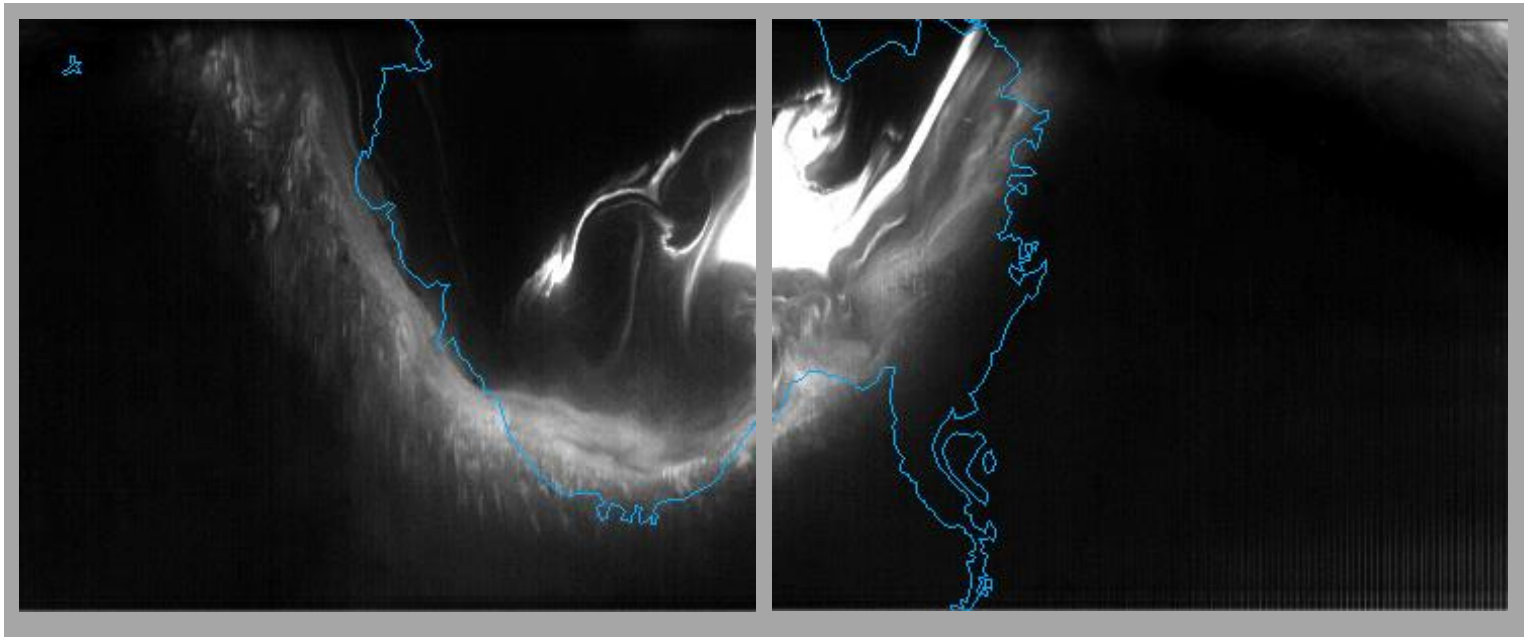
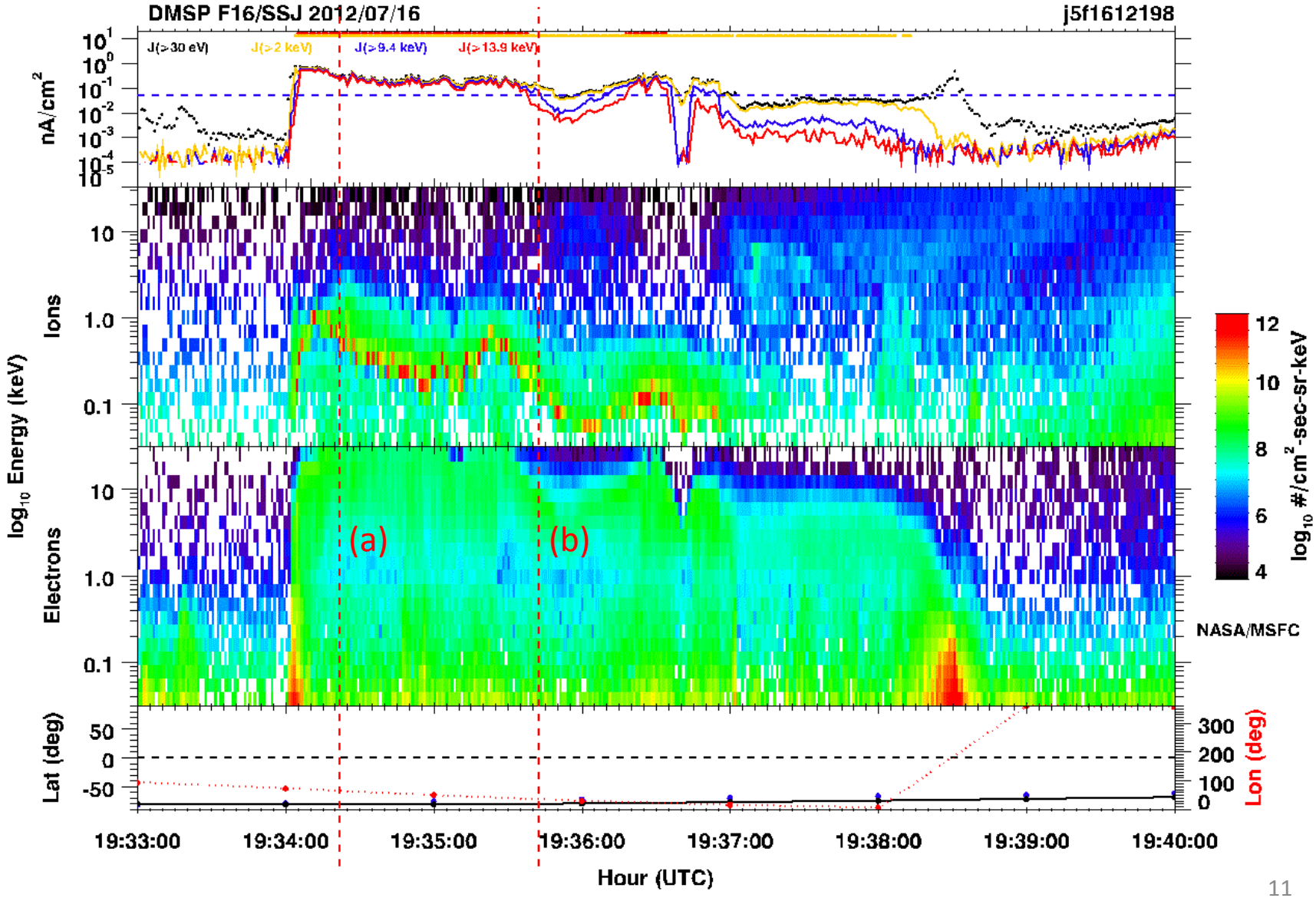


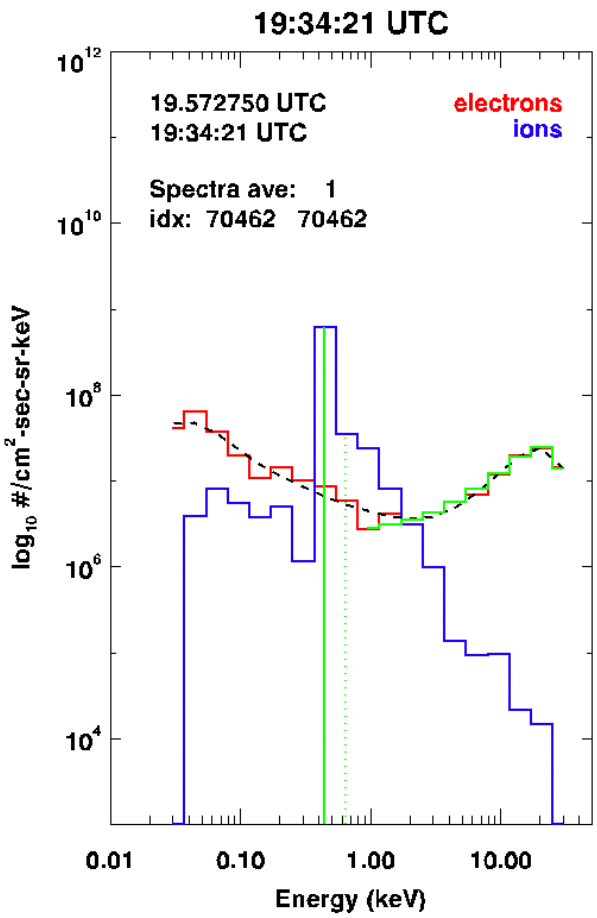


1995-07-25 01:33:42.0 1995-07-25 01:46:27.0 1995-07-25 01:59:12.0

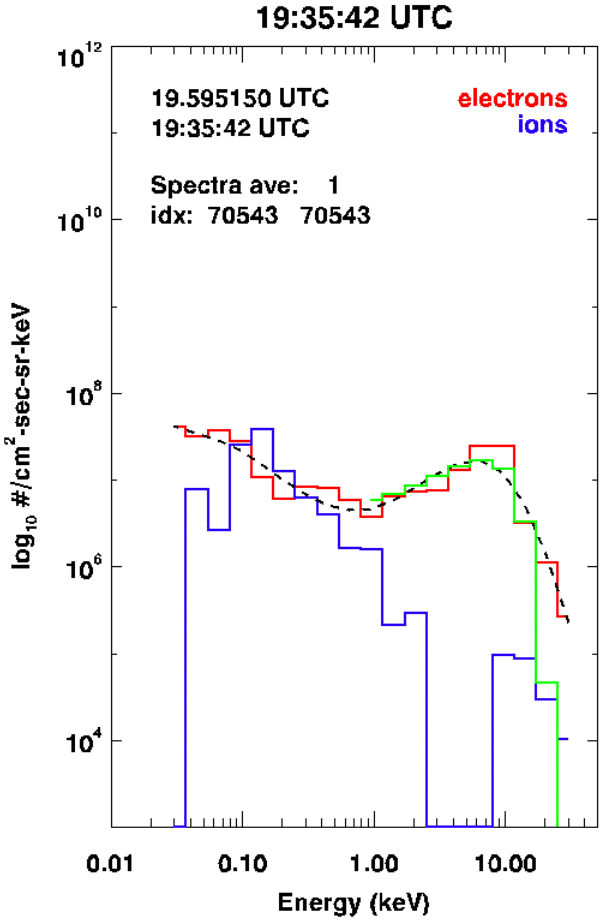
Individual Spectra



Individual Spectra



(a)



(b)

Fontheim Distribution

Ambient background

n=1.0e10	1/m3
Te=0.2	eV

Maxwellian

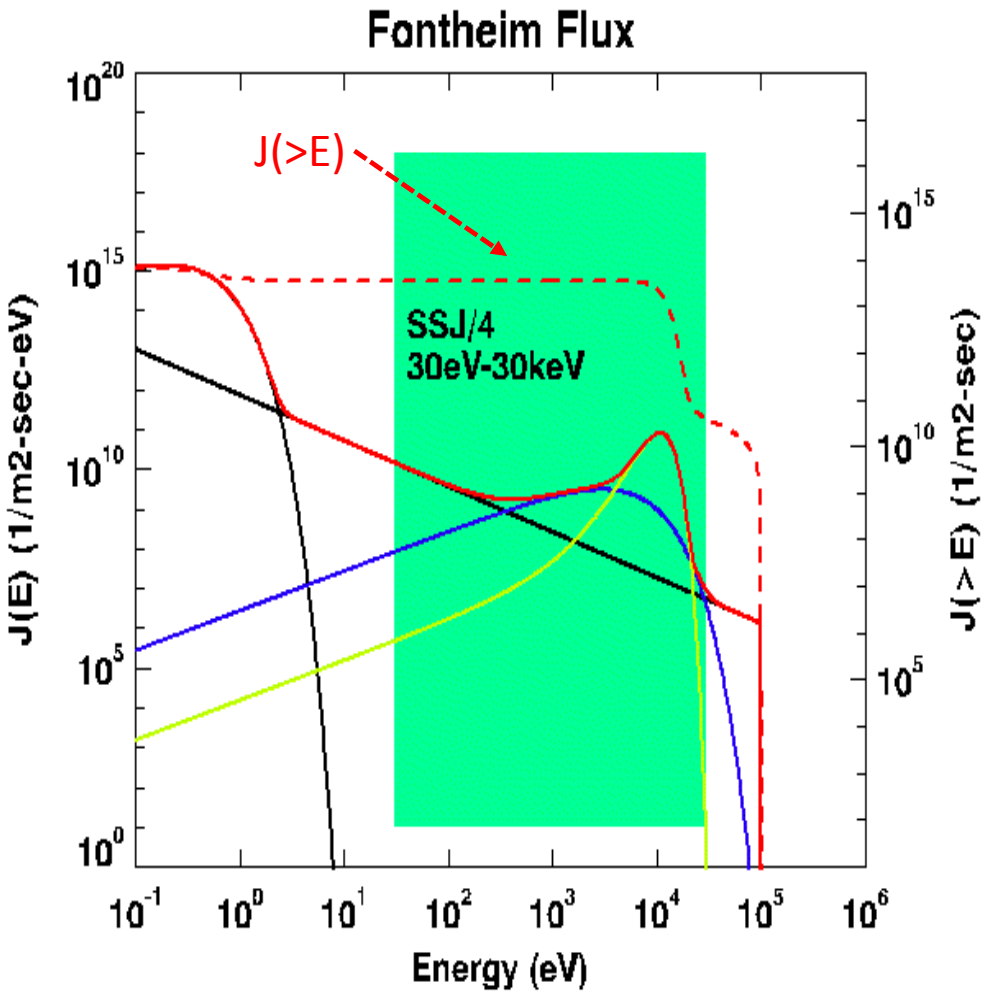
Jmax = 4.0e-6	A/m^2
Te = 3.0e3	eV

Gaussian (beam)

Jgau =0.9e-4	A/m^2	
Egau = 10.0e3	eV	beam energy
dgau = 4.0e3	eV	beam width

Power Law

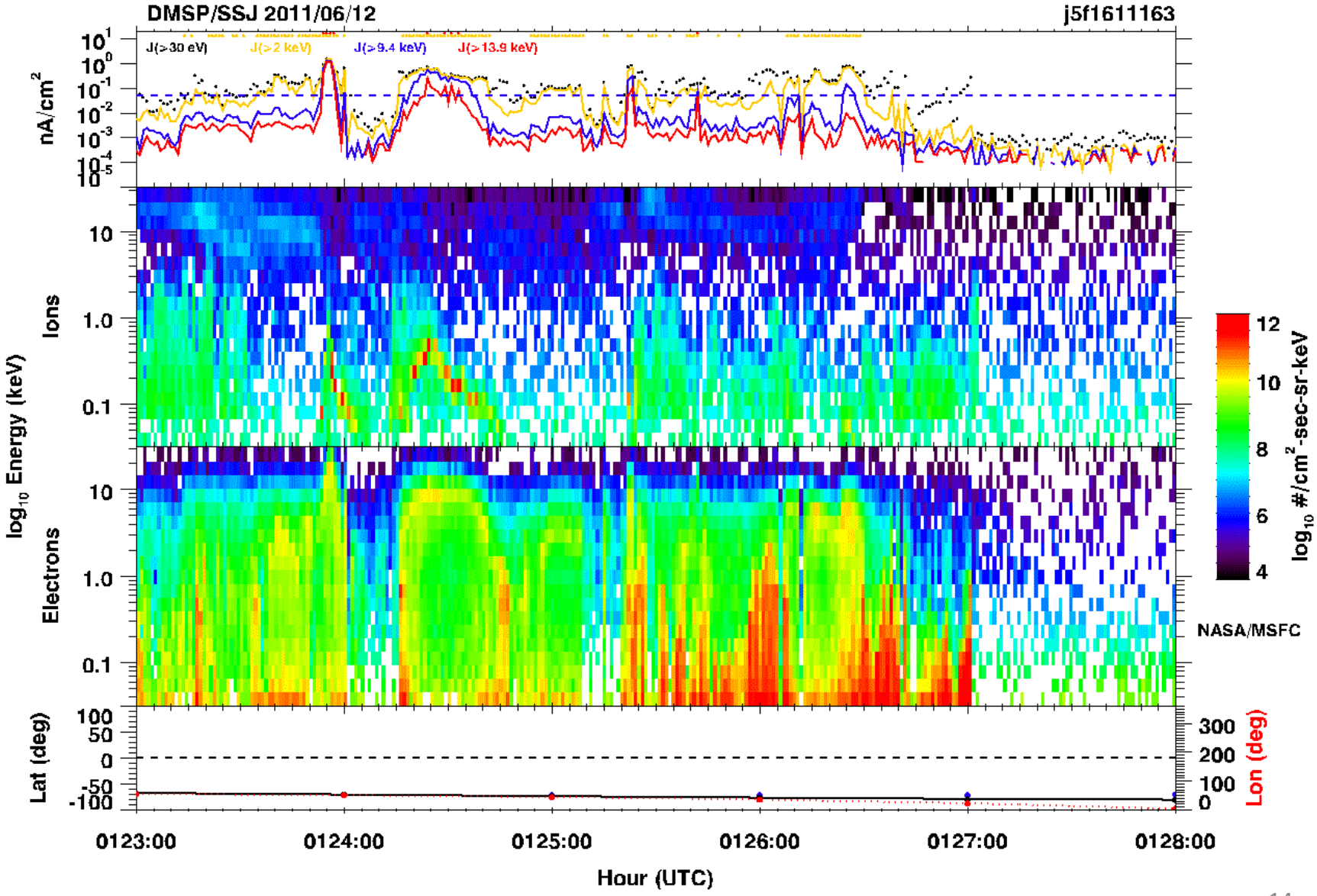
Jpwr = 3.0e-7	A/m^2
alpha = 1.15	exponent
E1=50.0	eV, first energy
E2=1.0e5	eV, second energy



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

[Davis et al., 2011]

Inverted V, Broadband Aurora

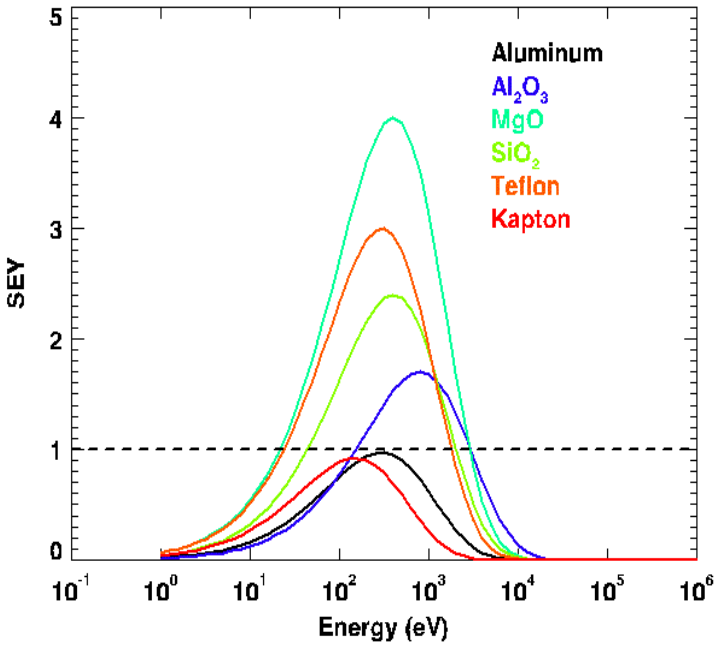


Secondary Electron Yields

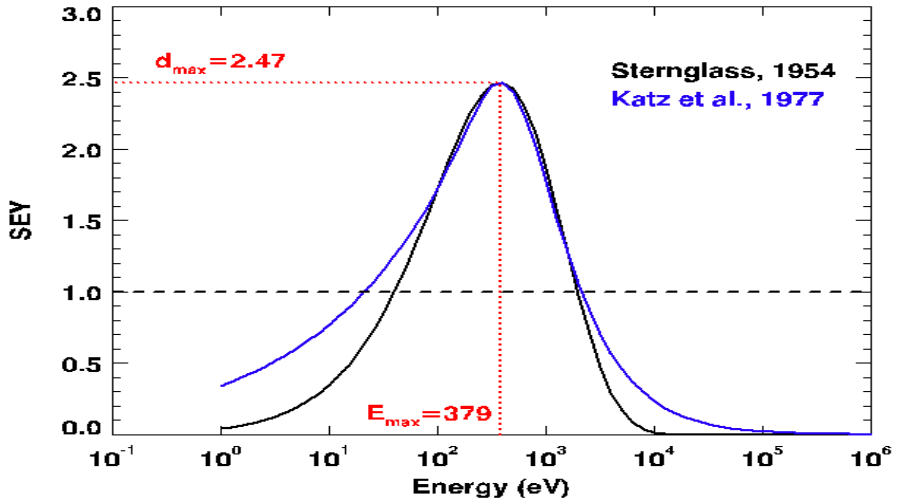
Charging is suppressed when SEY > 1

$$\frac{dQ}{dt} = \sum_k I_k = +I_i - I_e + I_{se} + I_{ph,e}$$

$$= +I_i - I_e(1-\delta) + I_{ph,e}$$



δ_m, E_m from Hasting and Garrett, 1996



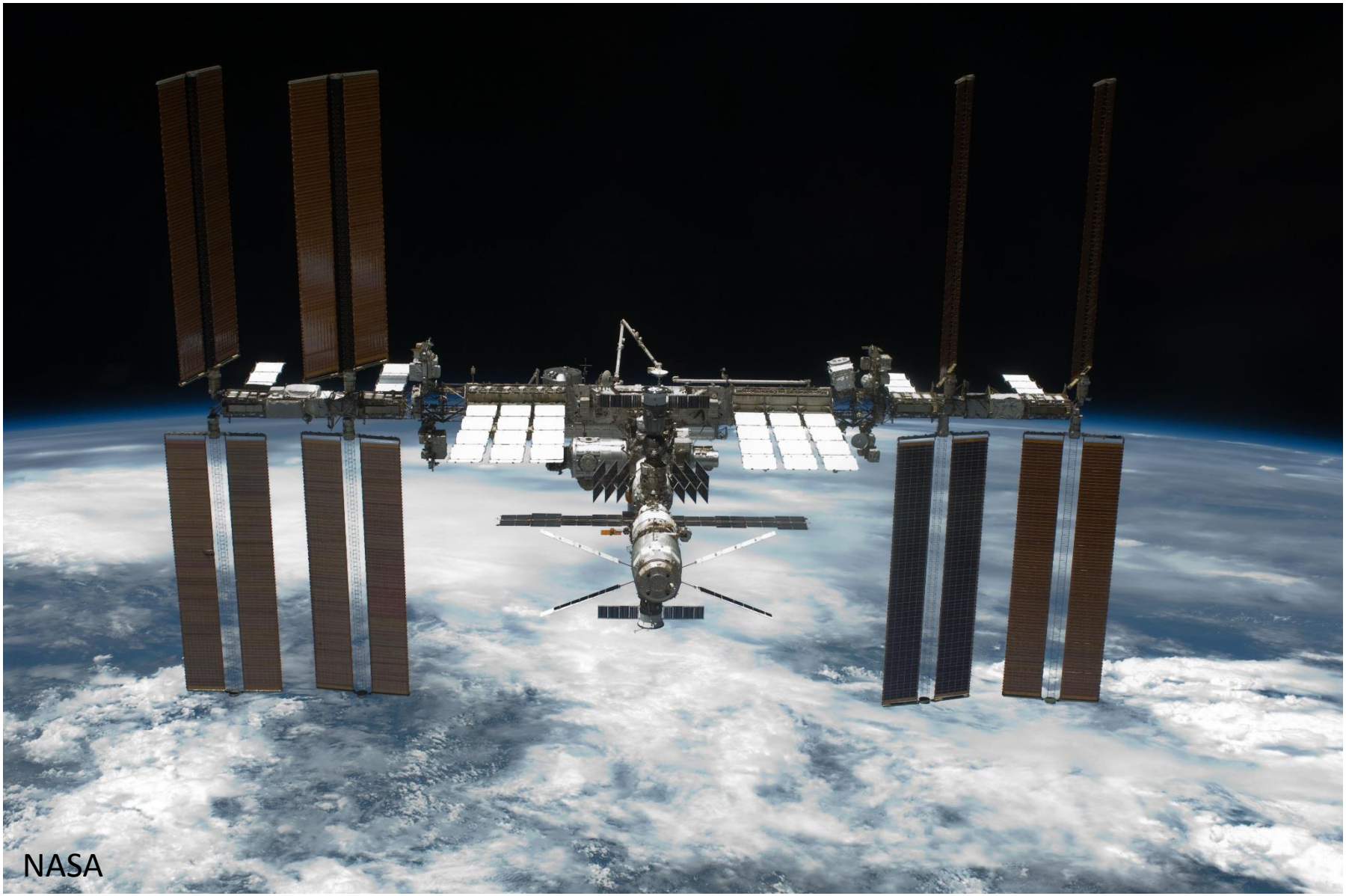
Sternglass, 1954

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

Katz et al., 1977; Whipple, 1981

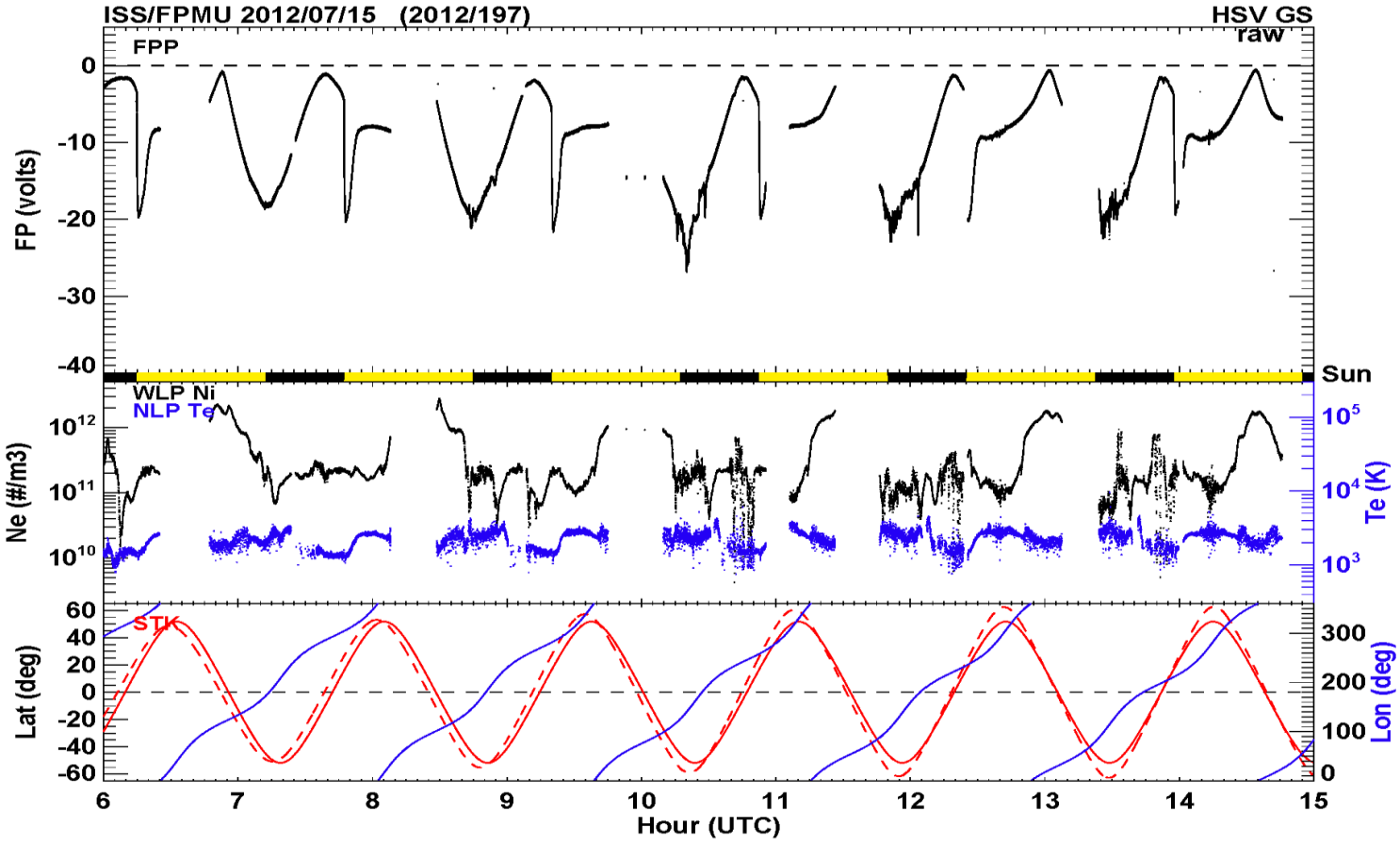
$$\delta_e(E,\theta) = \frac{1.114\delta_{e,\max}}{\cos\theta}\left[\frac{E}{E_{\max}}\right]^{0.35}\left\{1-\exp\left[-2.28\cos\theta\left[\frac{E_{\max}}{E}\right]^{1.35}\right]\right\}$$

ISS Charging



International Space Station: 15 July 2012

Potential variations due to (a) vxB.L (b) eclipse exit solar array (c) auroral charging



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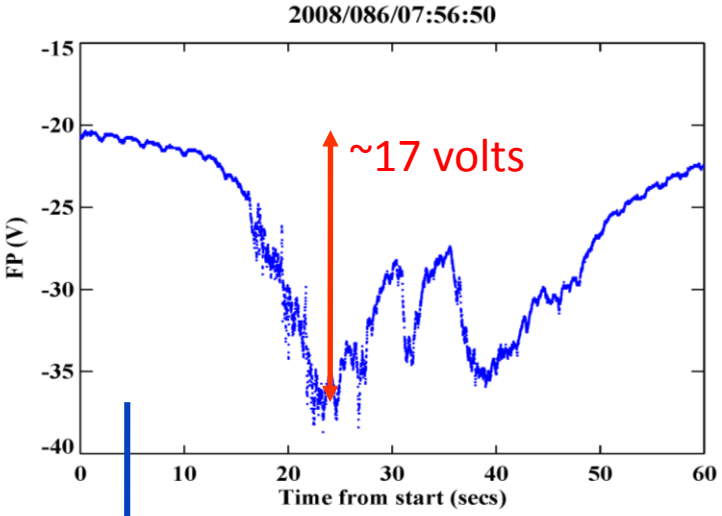
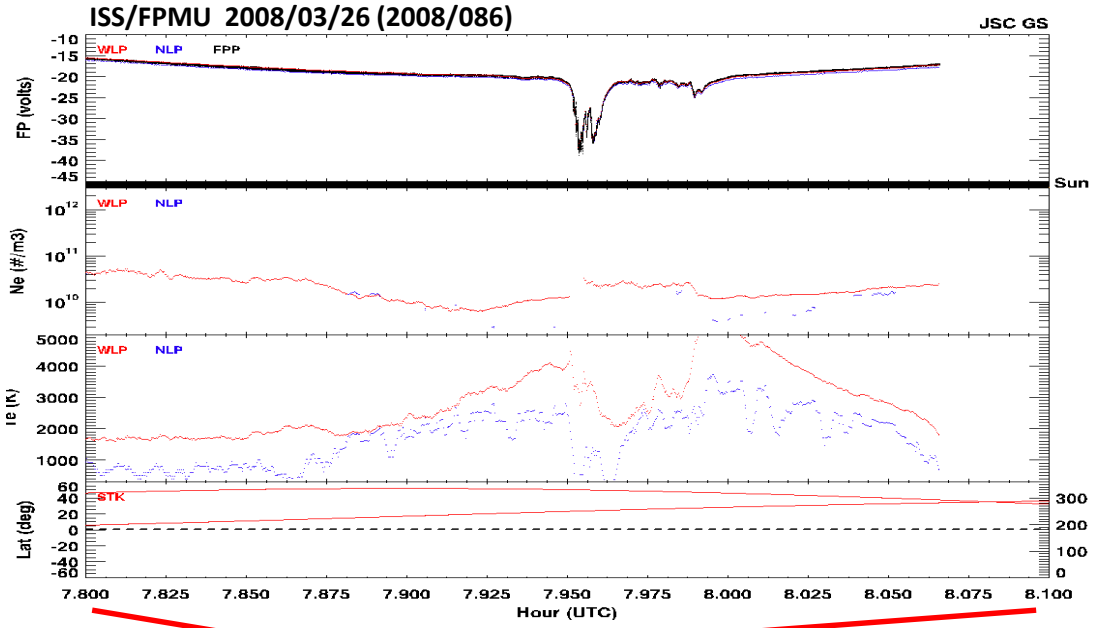
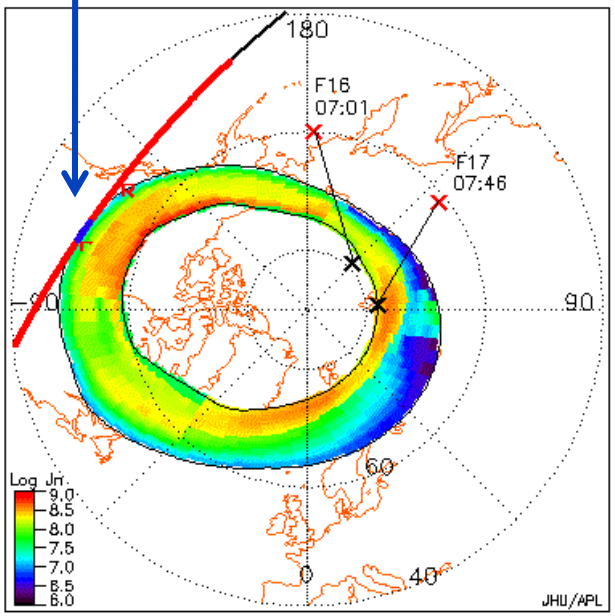
26 March 2008 -- Auroral Charging

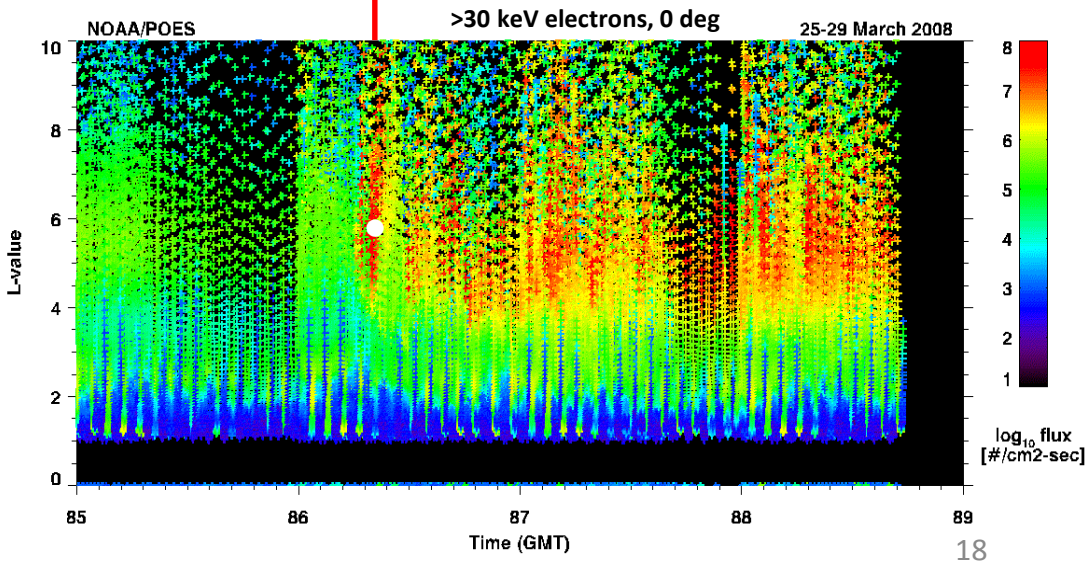




26 Mar 2008 07:30 – 08:00 UT



Normalized B2i = 62 Flux = 726 MWb
Equivalent Kp = 3.0 Global e– E–Flux = 23.0 MW



[adapted from *Craven et al.*, 2009]

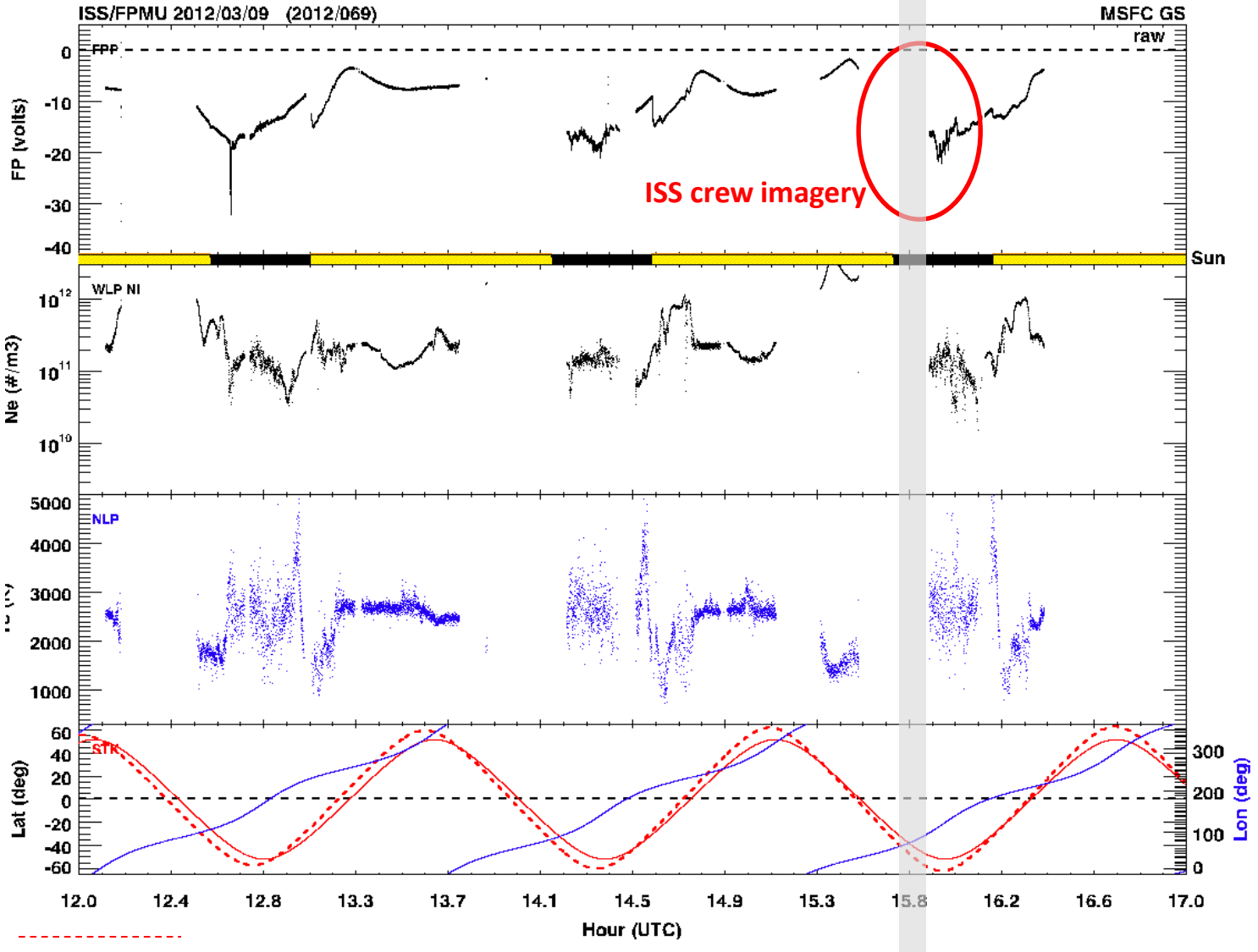
9 March 2012

$\Phi_{s/c}$

N_e

T_e

Lat/Lon



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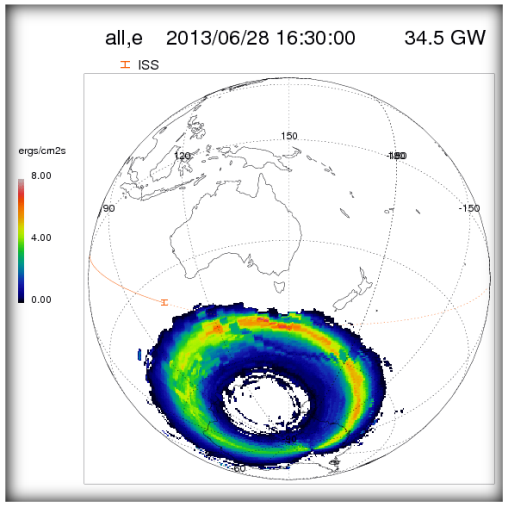
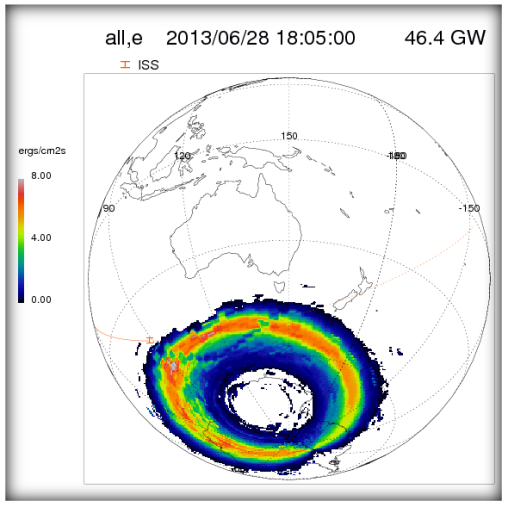
9 March 2012

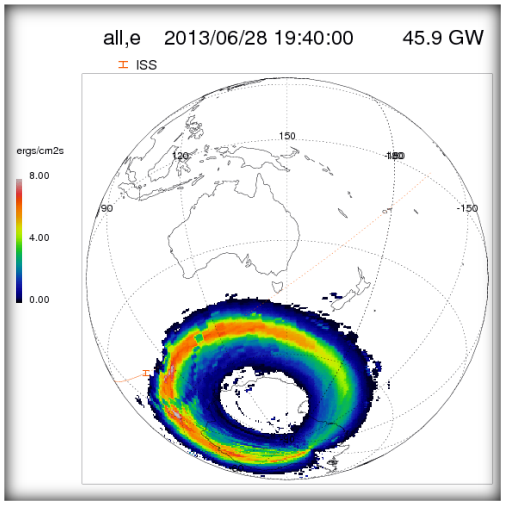
$\Phi_{s/c}$

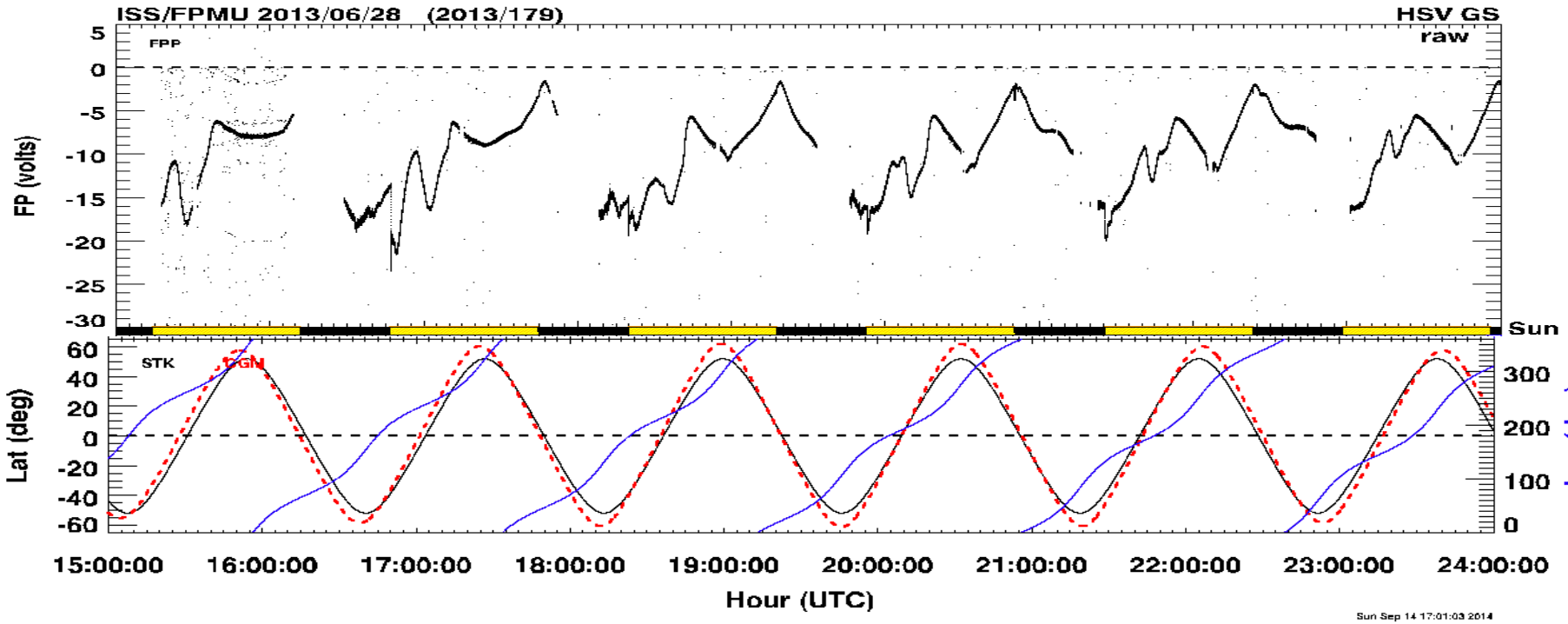
N_e

iSWA Ovation Prime, ISS Charging



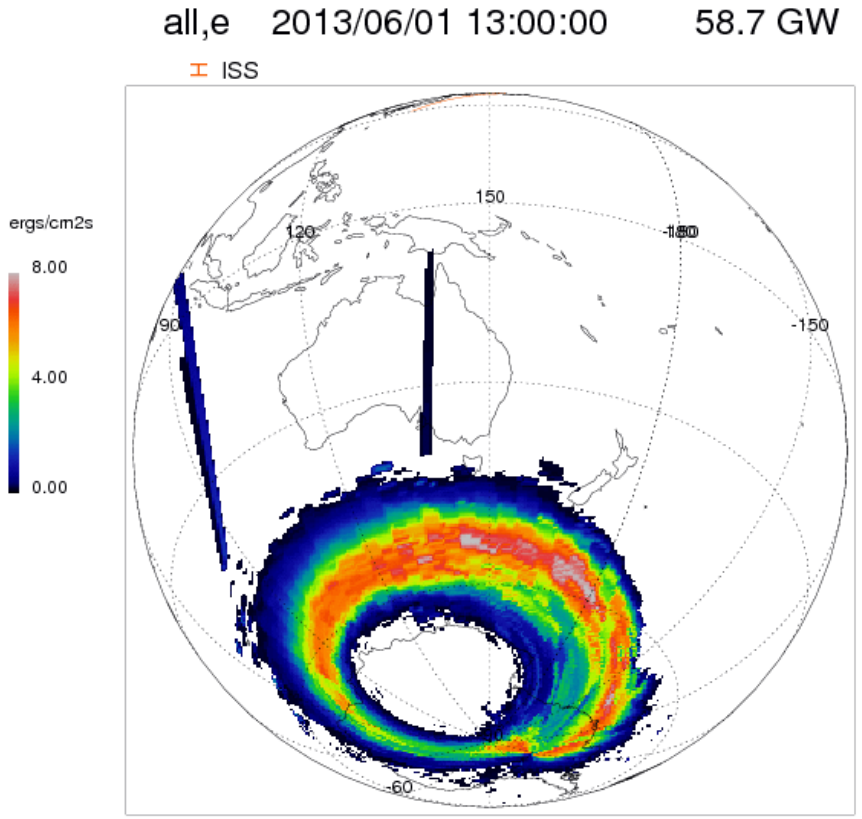




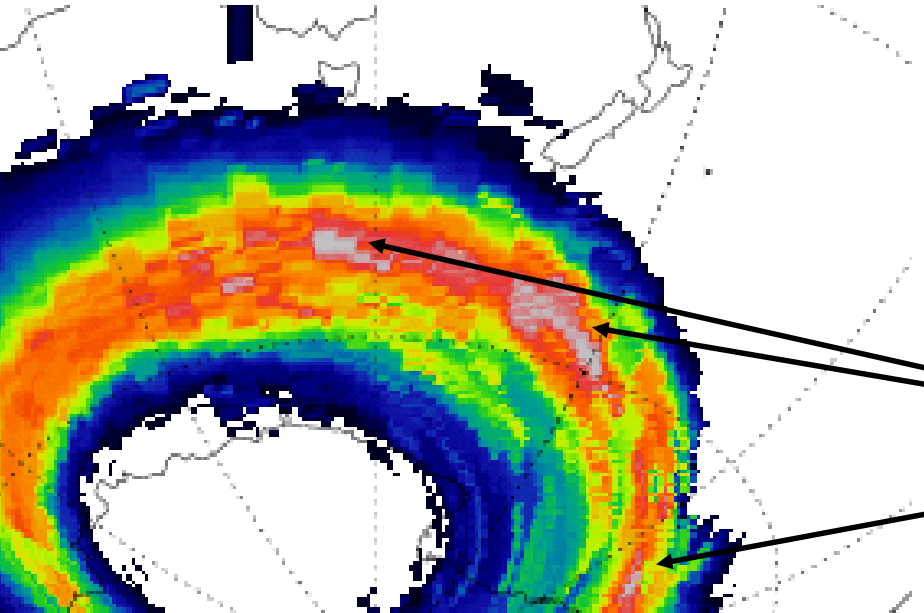


Aurora Models

- 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/cm^2-s (=mW/m^2)



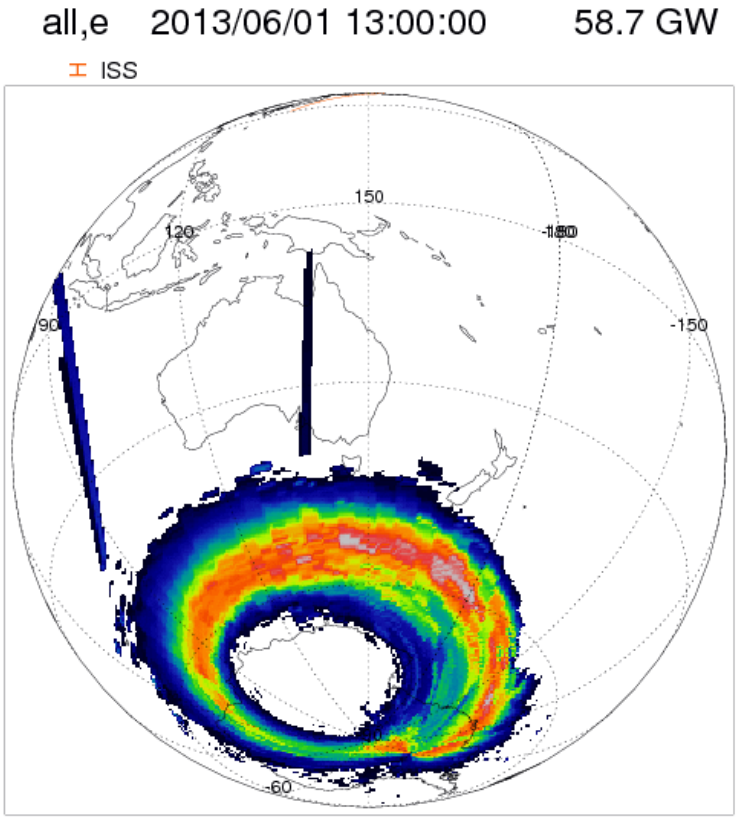
NASA CCMC



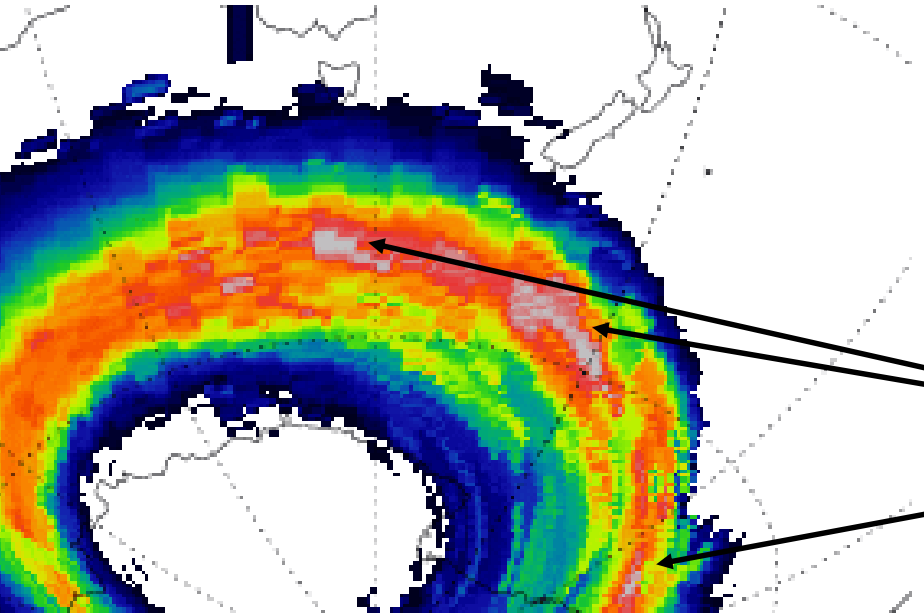
J ≥ 8 ergs/cm^2-s

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/cm2-s to consider auroral charging regime
- Energy flux for J_E(≥10 keV) erg/cm^2-s

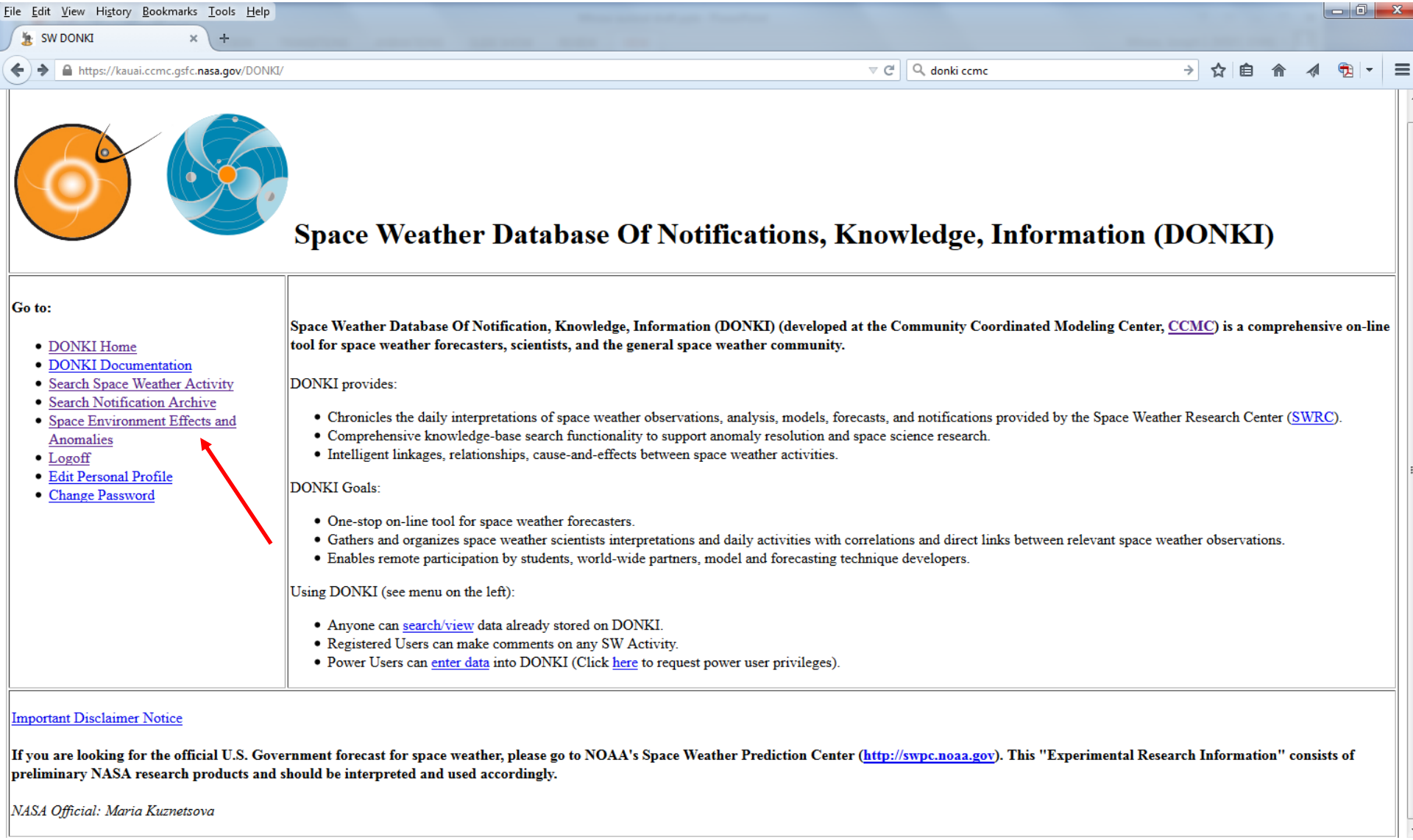


NASA CCMC



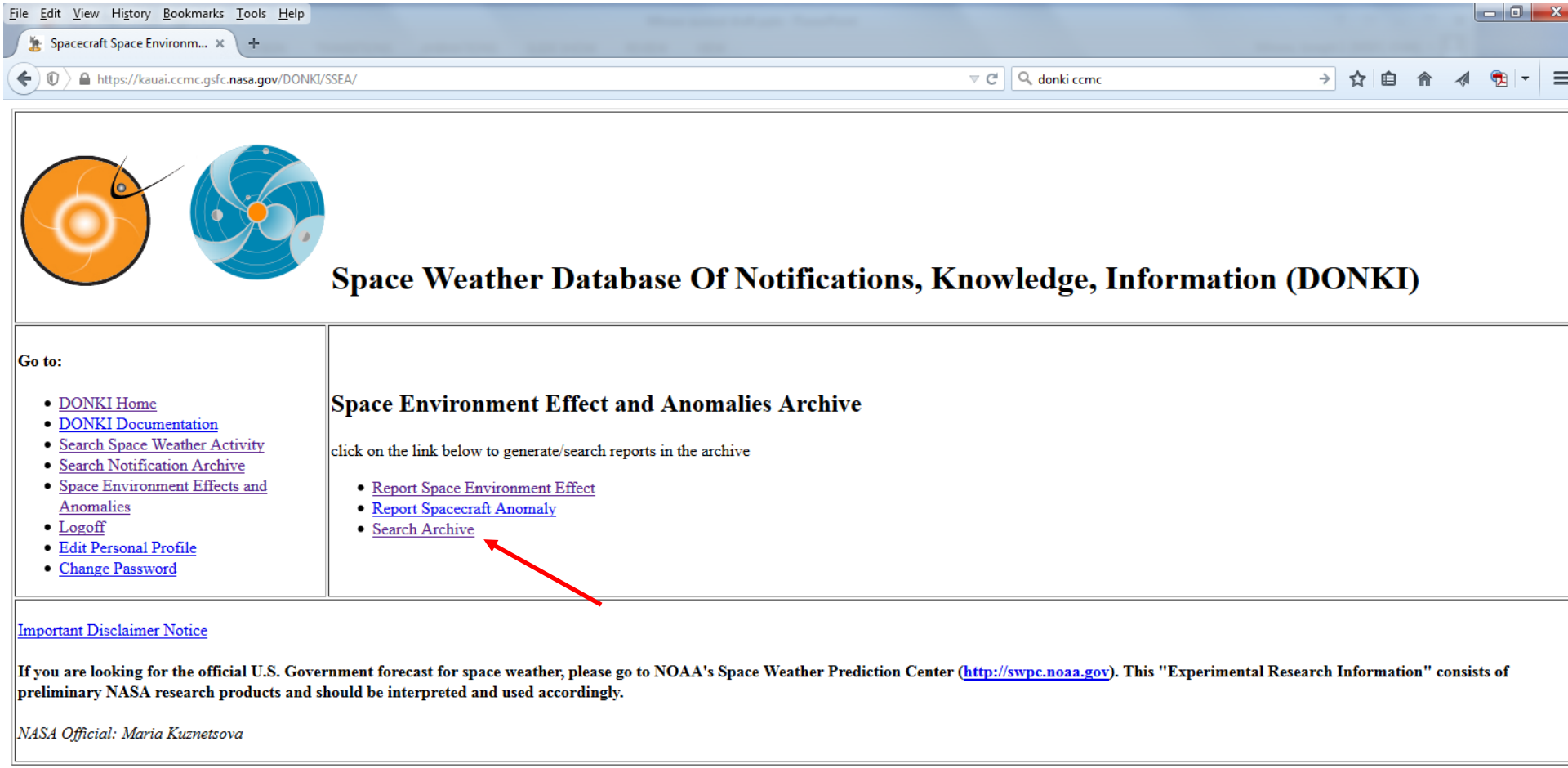
J ≥ 8 ergs/cm^2-s

CCMC DONKI

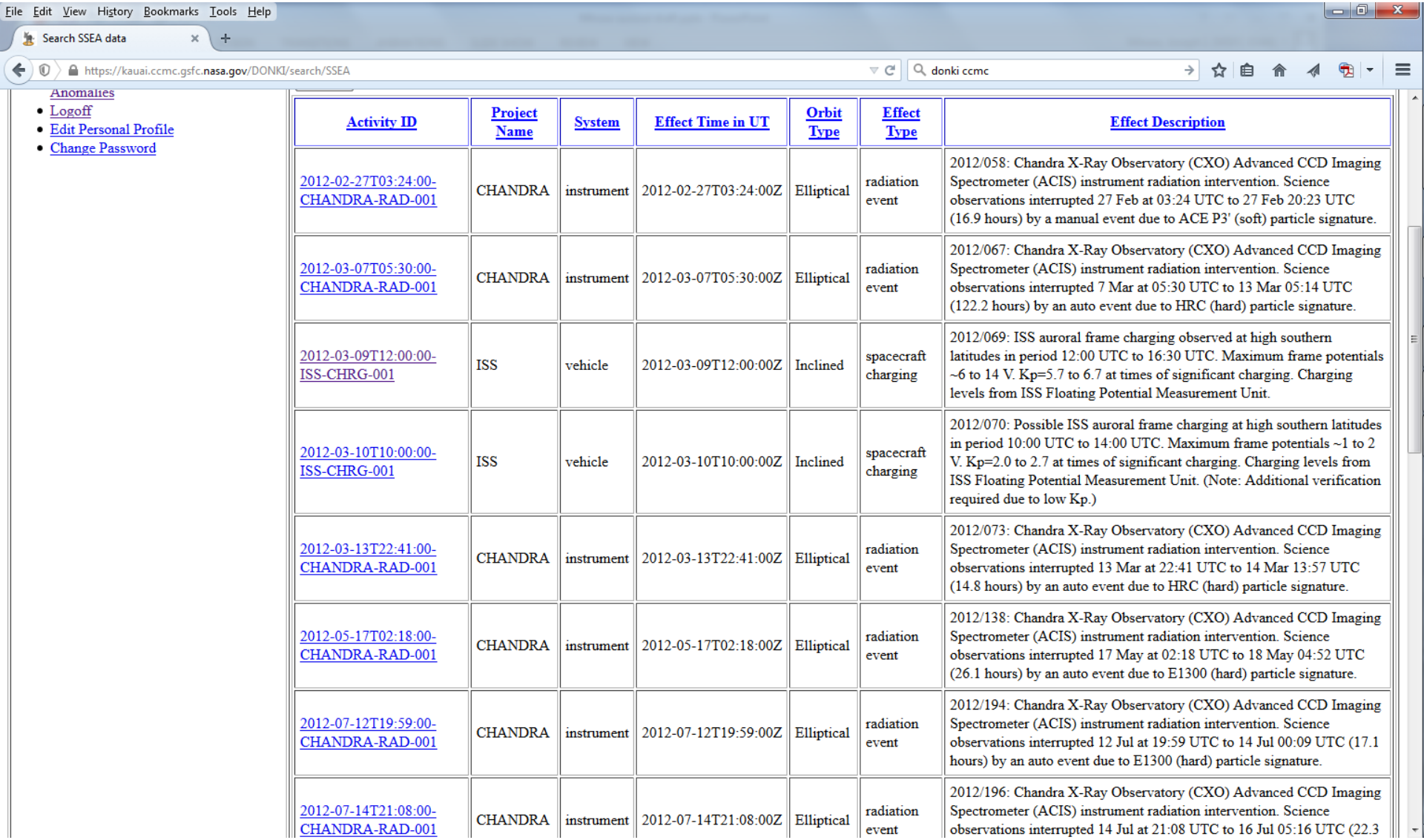


http://kauai.ccmc.gsfc.nasa.gov/DONKI/

Space Environment Effect and Anomalies Archive



CCMC SSEA



Activity ID	Project Name	System	Effect Time in UT	Orbit Type	Effect Type	Effect Description
2012-02-27T03:24:00-CHANDRA-RAD-001	CHANDRA	instrument	2012-02-27T03:24:00Z	Elliptical	radiation event	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.
2012-03-07T05:30:00-CHANDRA-RAD-001	CHANDRA	instrument	2012-03-07T05:30:00Z	Elliptical	radiation event	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.
2012-03-09T12:00:00-ISS-CHRG-001	ISS	vehicle	2012-03-09T12:00:00Z	Inclined	spacecraft charging	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.
2012-03-10T10:00:00-ISS-CHRG-001	ISS	vehicle	2012-03-10T10:00:00Z	Inclined	spacecraft charging	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.)
2012-03-13T22:41:00-CHANDRA-RAD-001	CHANDRA	instrument	2012-03-13T22:41:00Z	Elliptical	radiation event	2012/073: Chandra X-Ray Observatory (CXO) Advanced CCD Imaging Spectrometer (ACIS) instrument radiation intervention. Science observations interrupted 13 Mar at 22:41 UTC to 14 Mar 13:57 UTC (14.8 hours) by an auto event due to HRC (hard) particle signature.
2012-05-17T02:18:00-CHANDRA-RAD-001	CHANDRA	instrument	2012-05-17T02:18:00Z	Elliptical	radiation event	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.
2012-07-12T19:59:00-CHANDRA-RAD-001	CHANDRA	instrument	2012-07-12T19:59:00Z	Elliptical	radiation event	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.
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

File Edit View History Bookmarks Tools Help

View Space Weather Activity

https://kauai.ccmc.gsfc.nasa.gov/DONKI/view/SEeffectReport/6829/1

donki ccmc

Go to:

- DONKI Home
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- Search Space Weather Activity
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- Logoff
- Edit Personal Profile
- Change Password

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) NOAA Kp: 6 (2012-03-09T12:00Z)	DELETE

Post a Comment:

Space Environment Effect Report

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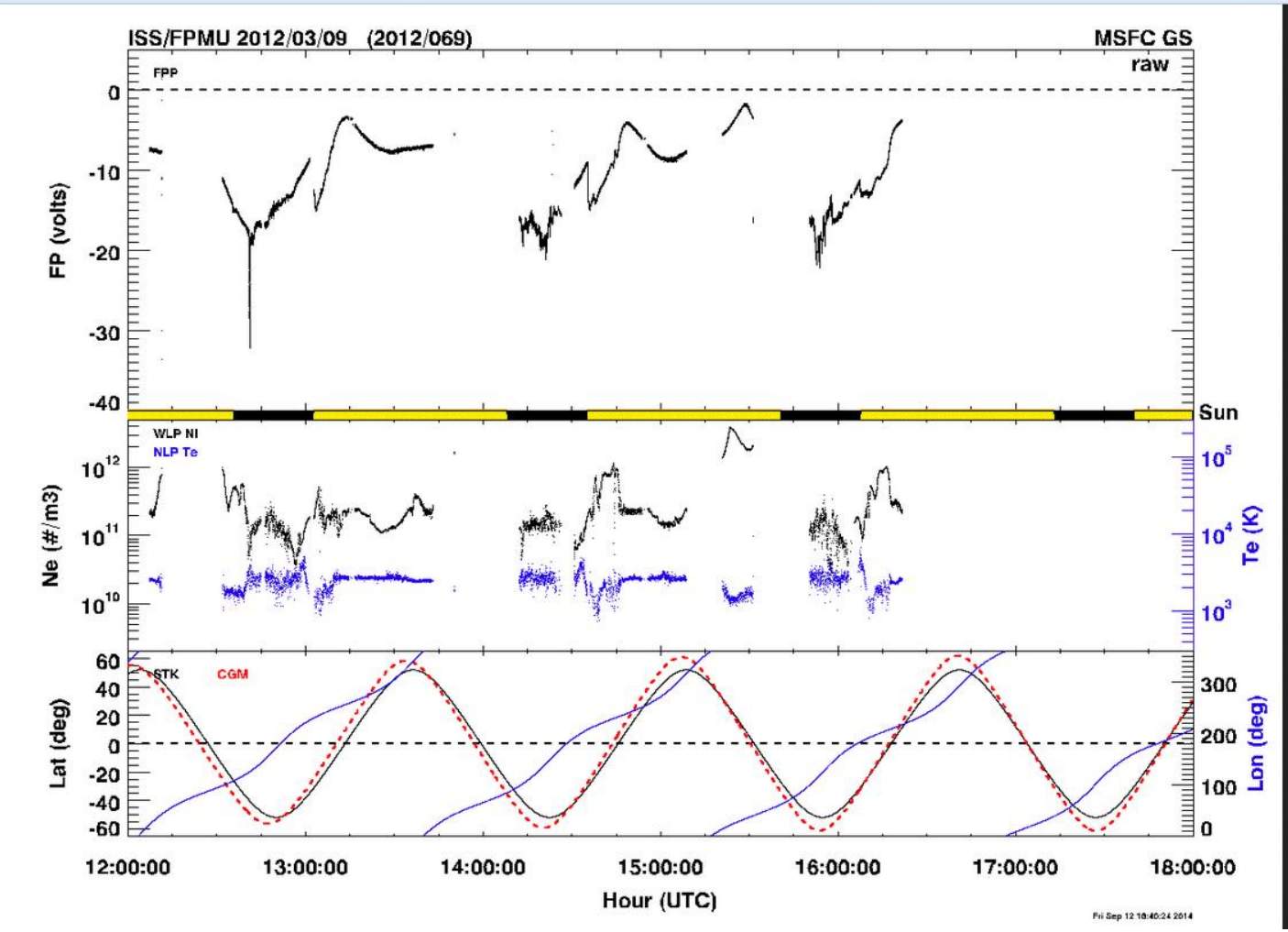
AS_2012_069_1200_1800.png (P...

https://kauai.ccmc.gsfc.nasa.gov/DONKI/resources/images/protected/AS_2012_069_1200_1800.png

donki ccmc




Questions?
iss030e131395.jpg
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