Auroral Charging and Characteristics of Auroral Charging Environments

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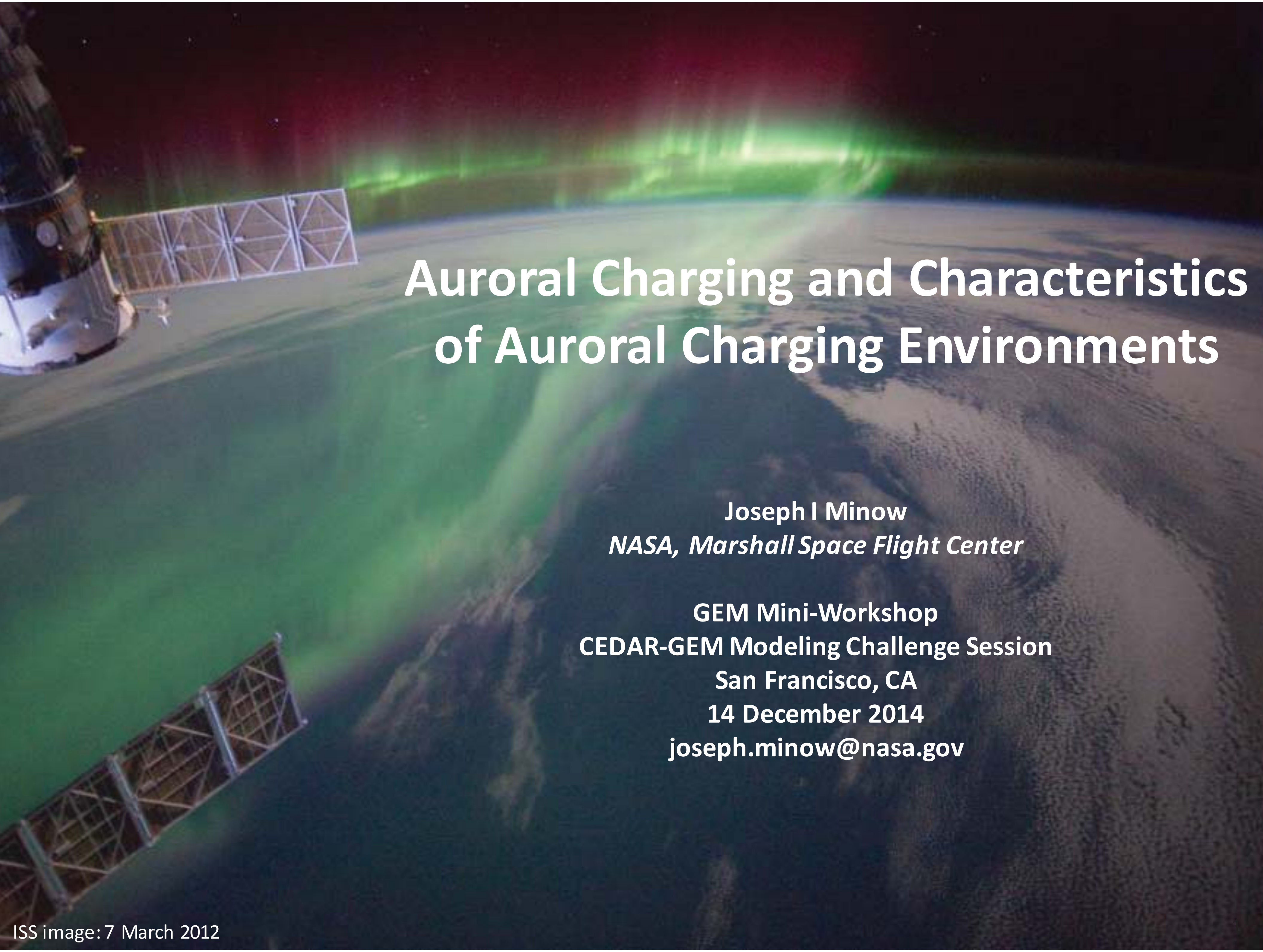
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Introduction

Today's presentation is a short tutorial on auroral charging of spacecraft and the characteristics of the space plasma environment that are required to predict charging

Outline

- Physics of surface charging
- Examples of auroral charging and auroral charging environments
- Electron, ion energy spectra during charging events
- Space weather model outputs required for predicting auroral charging

Acknowledgements:

DMSP SSJ, SSIES, and OLS records are provided by the US Air Force and NOAA's National Geophysical Data Center.

Potential Distributions on Spacecraft Surfaces

- **Electrostatic potentials**
  - Due to net charge density on spacecraft surfaces of or within insulating materials due to current collection to/from the space environment
  - Examples include
    - Plasma currents to surface
    - Secondary electron currents
    - Photoelectron currents
    - Solar array current collection
    - Active current sources (Electron, ion beams, electric thrusters, plasma contactors)
    - Energetic (~MeV) electrons
- **Electrodynamic (inductive) potentials**
  - Modification of frame potentials without change in net charge on spacecraft
  - Plasma environment not required
  - Examples include
    - EMF generated by motion of conductor through magnetic field
    - Externally applied electric fields

Surface charging

$$\frac{dQ}{dt} = C\frac{d\phi}{dt} = \sum_{k} I_k$$

~ 0 at equilibrium

Internal (deep dielectric) charging

$$\vec{\nabla}\cdot\vec{D} = \vec{\nabla}\cdot\varepsilon\vec{E} = \vec{\nabla}\cdot\varepsilon(-\vec{\nabla}\phi) = \rho$$

$$\nabla^2\phi = -{}^{\rho}\!/\!{}_{\varepsilon}$$

$$\frac{\partial\rho}{\partial t} = -\nabla\cdot J \quad \text{where } J = J_R + J_C$$

$\vec{F} = q(\vec{E} + \vec{v}\times\vec{B})$ Laboratory frame

$\vec{F}' = q\vec{E}'$ Spacecraft rest frame

$\vec{E}' = \vec{E} + \vec{v}\times\vec{B}$ Forces equal in both frames!

$$\varepsilon'_m = \oint_C \vec{E}'\cdot d\vec{S} = \oint_C (\vec{E} + \vec{v}\times\vec{B})\cdot d\vec{S}$$

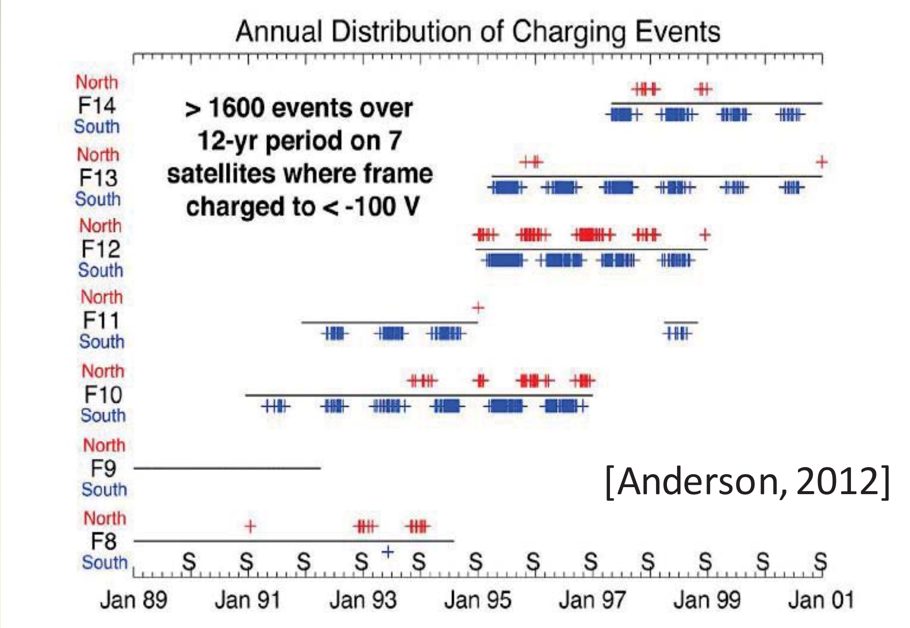
$$\Delta\phi' = \oint_C (\vec{E} + \vec{v}\times\vec{B})\cdot d\vec{S}$$

[c.f., *Whipple*, 1981; p. 272 *Wangness*, 1986; p. 210 *Jackson*, 1975; *Maynard*, 1998]

Auroral Charging Conditions

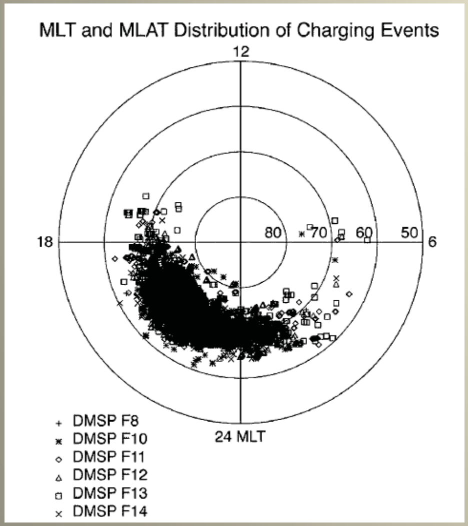
Necessary conditions for high-level (≥100 V) auroral charging*

- 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)

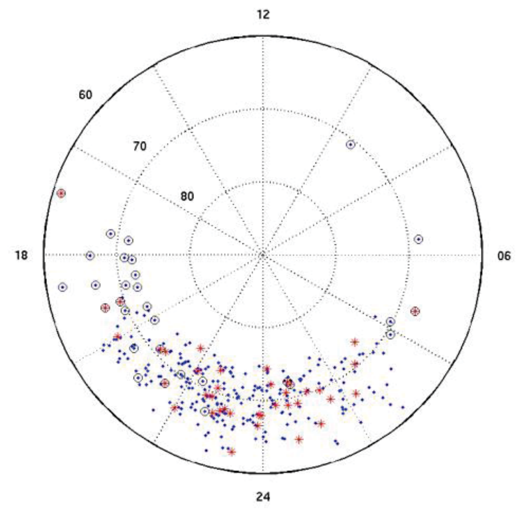


> 1600 events over 12-yr period on 7 satellites where frame charged to < -100 V

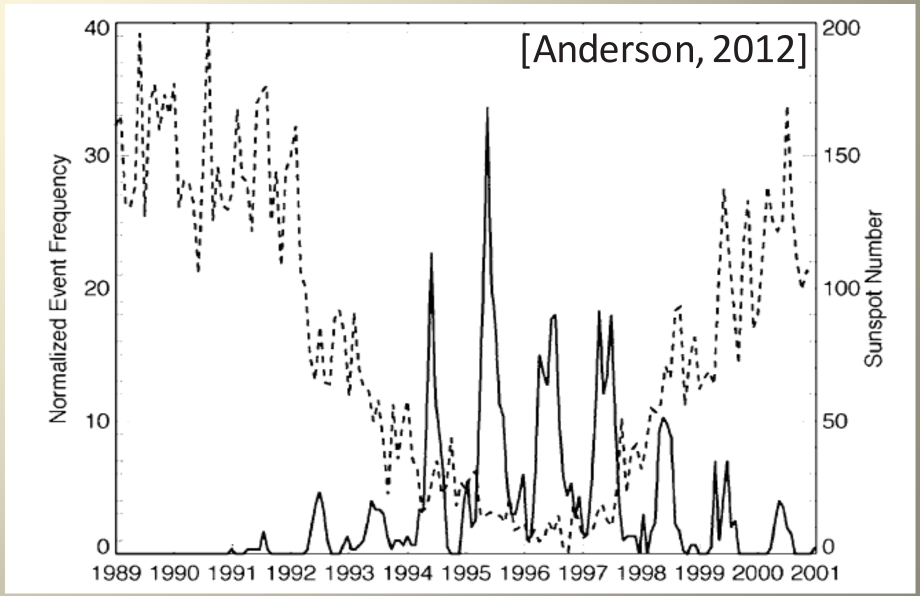
[Anderson, 2012]



[Anderson, 2012]



[Eriksson and Wahlund, 2006]



[Anderson, 2012]

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

Surface Charging Physics

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

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

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

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

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

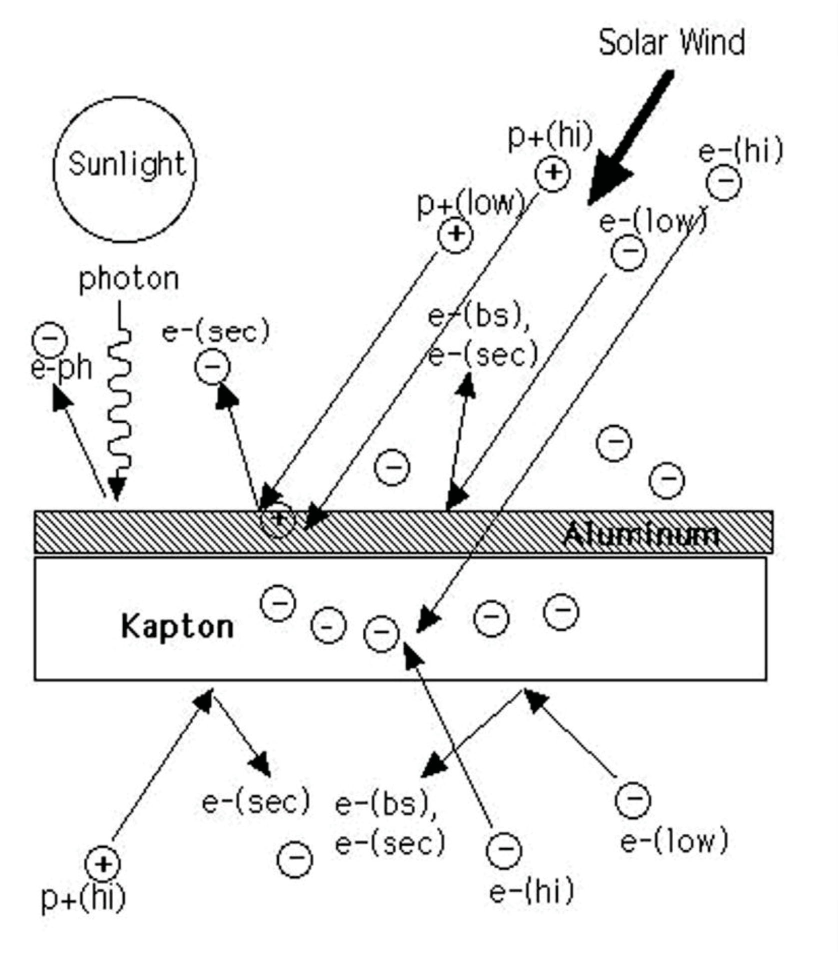
$+I_{bs,e}(V)$ **backscattered electrons**

$+I_c(V)$ **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**



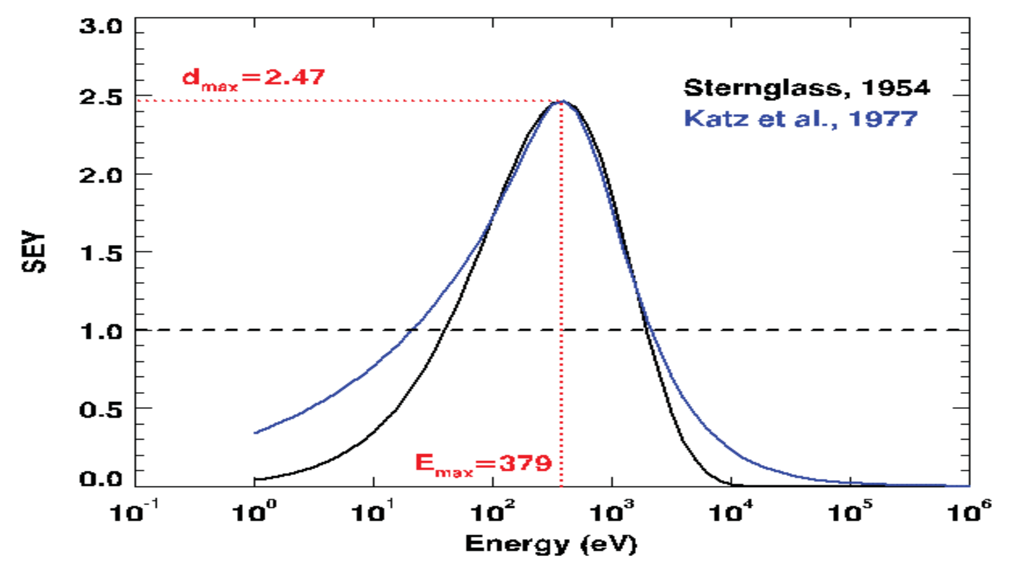
(Garrett and Minow, 2004)

Secondary Electron Yields

Charging is suppressed when SEY > 1

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

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

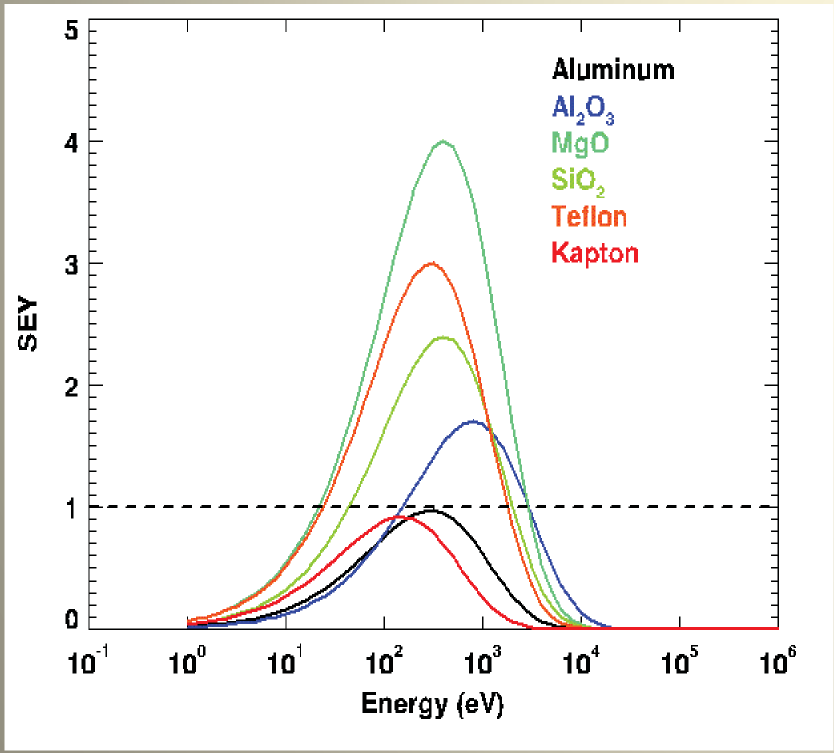


Sternglass, 1954

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

Katz et al., 1977; Whipple, 1981

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



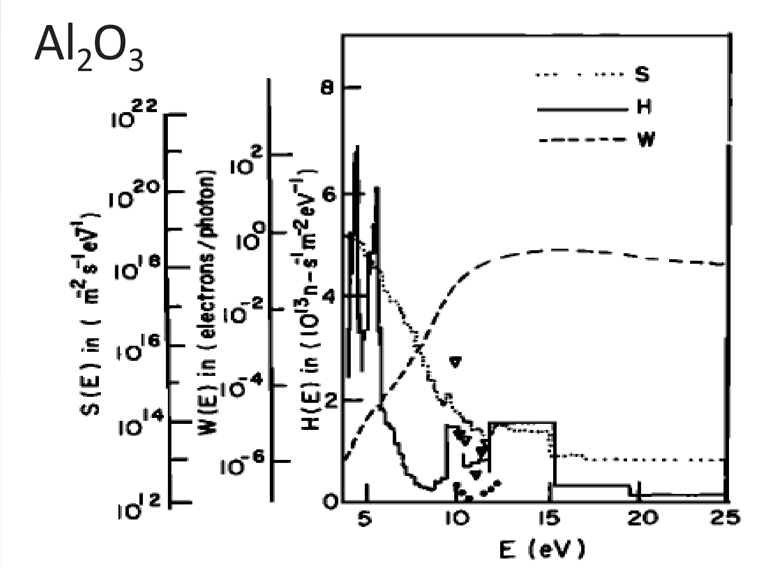
δ_m, E_m from Hasting and Garrett, 1996

Photoemission Yields

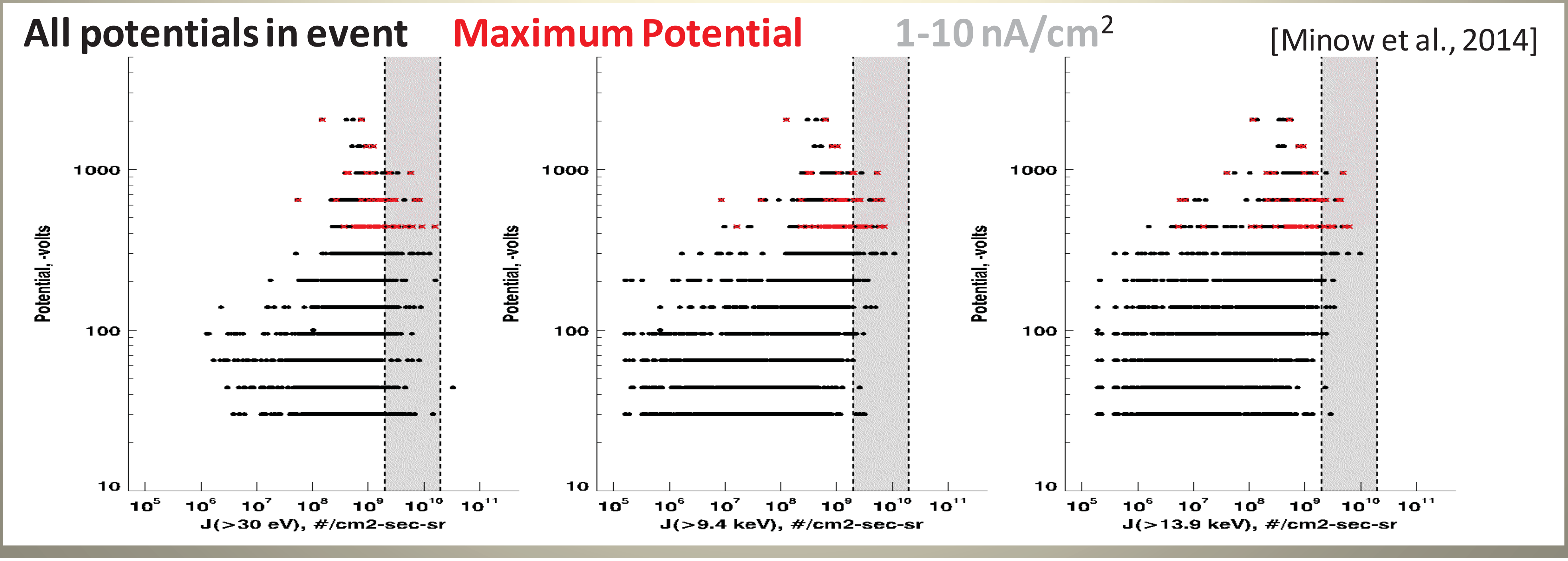
- Photoemission is an important factor in controlling surface charging

Material	Saturation Photocurrent Density
Al2O3	4.2 nA/cm^2
Au	2.9 nA/cm^2
Stainless steel	2.0 nA/cm^2
Graphite	0.4 nA/cm^2

[from Garrett, 1981]



[Grard, 1973]



[Minow et al., 2014]

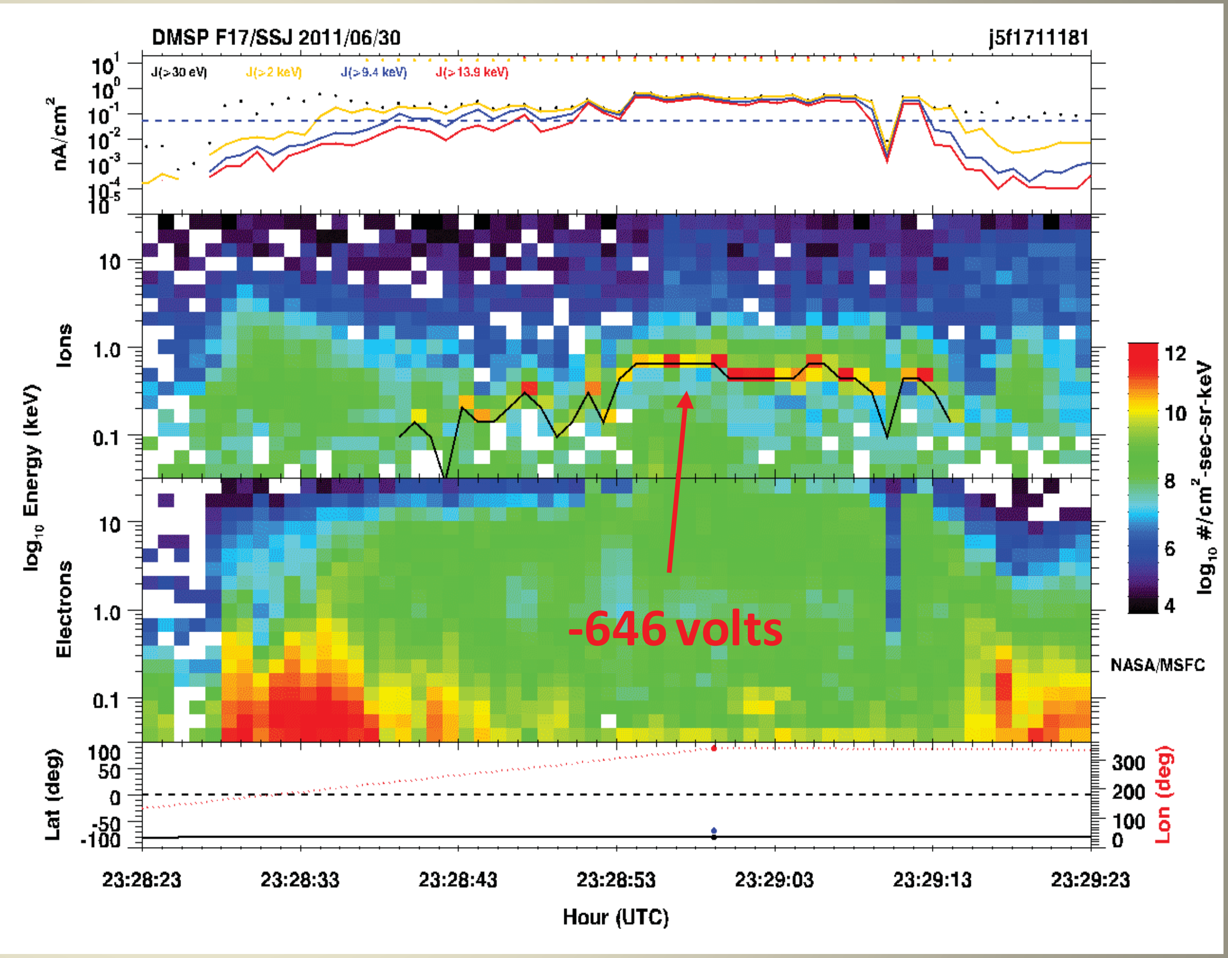
“Ion Line” Charging Signature

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

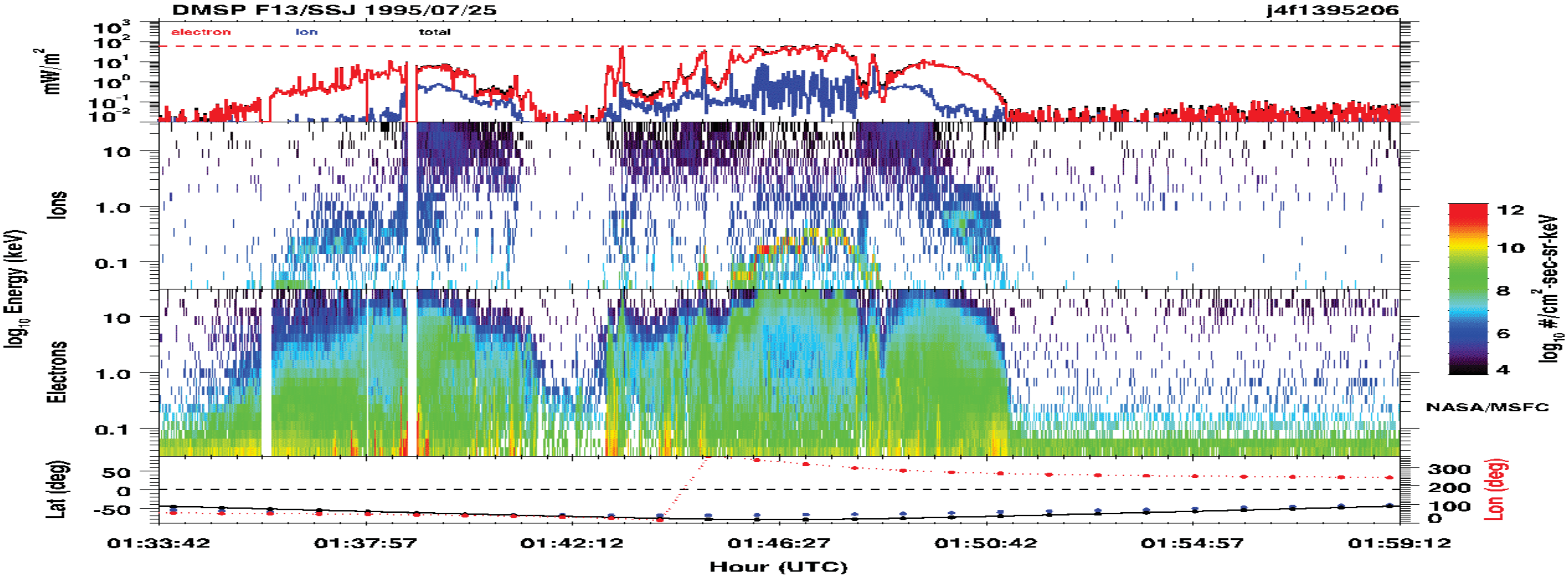
$$E = E_0 + q\Phi$$

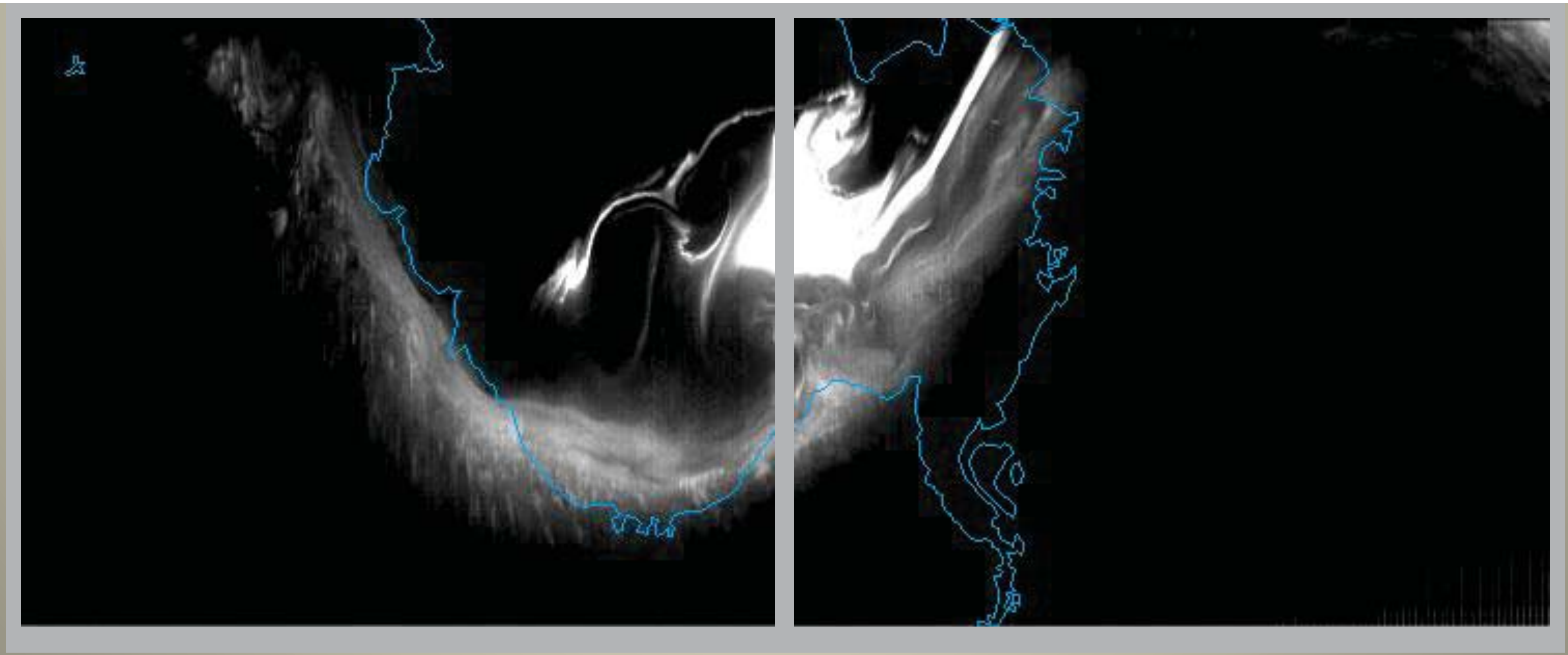
- Assume initial energy $E_0 = 0$ with singly charge ions (O^+, H^+) and read potential (volts) directly from ion line energy (eV)

- 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



-646 volts

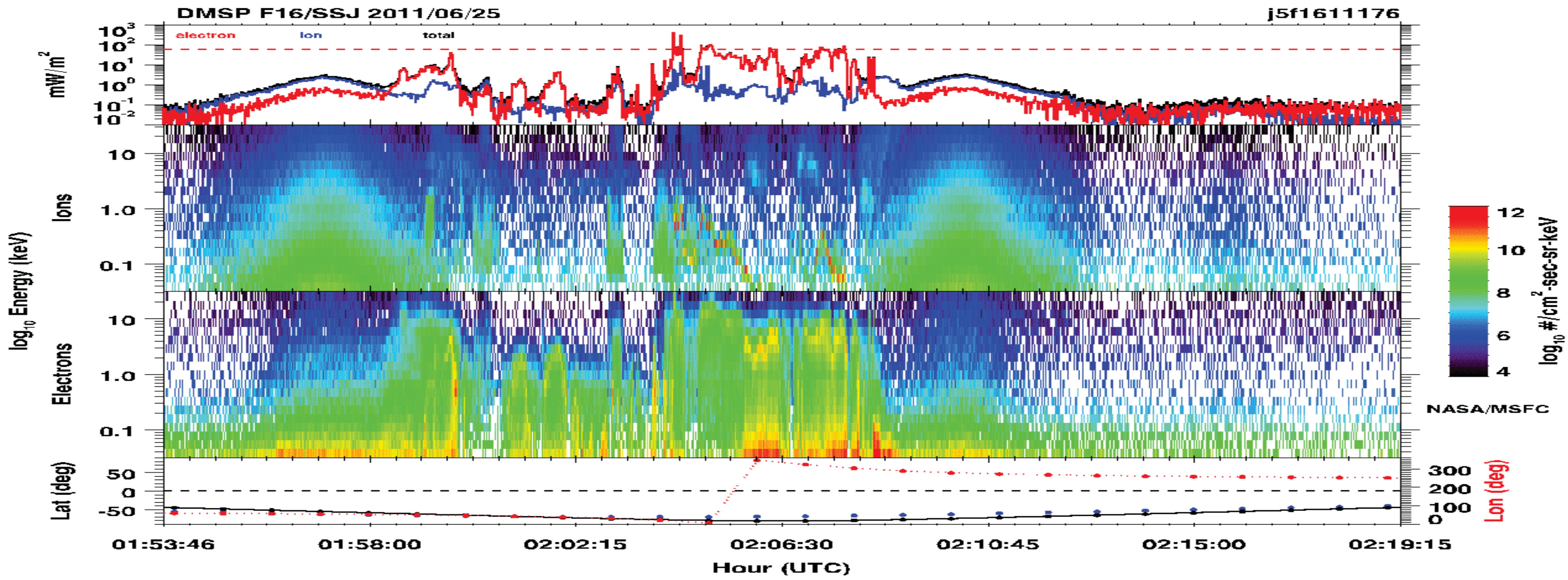


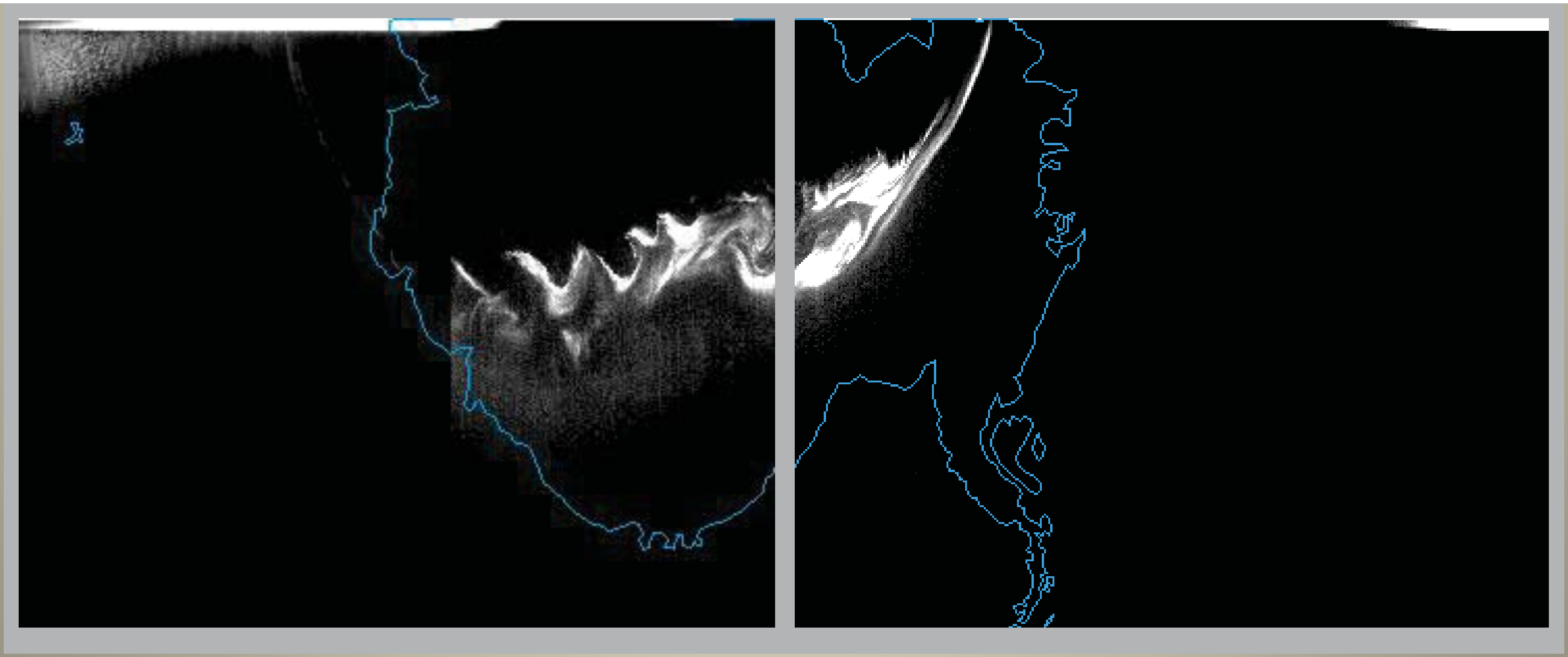


1995-07-25 01:33:42.0

1995-07-25 01:46:27.0

1995-07-25 01:59:12.0

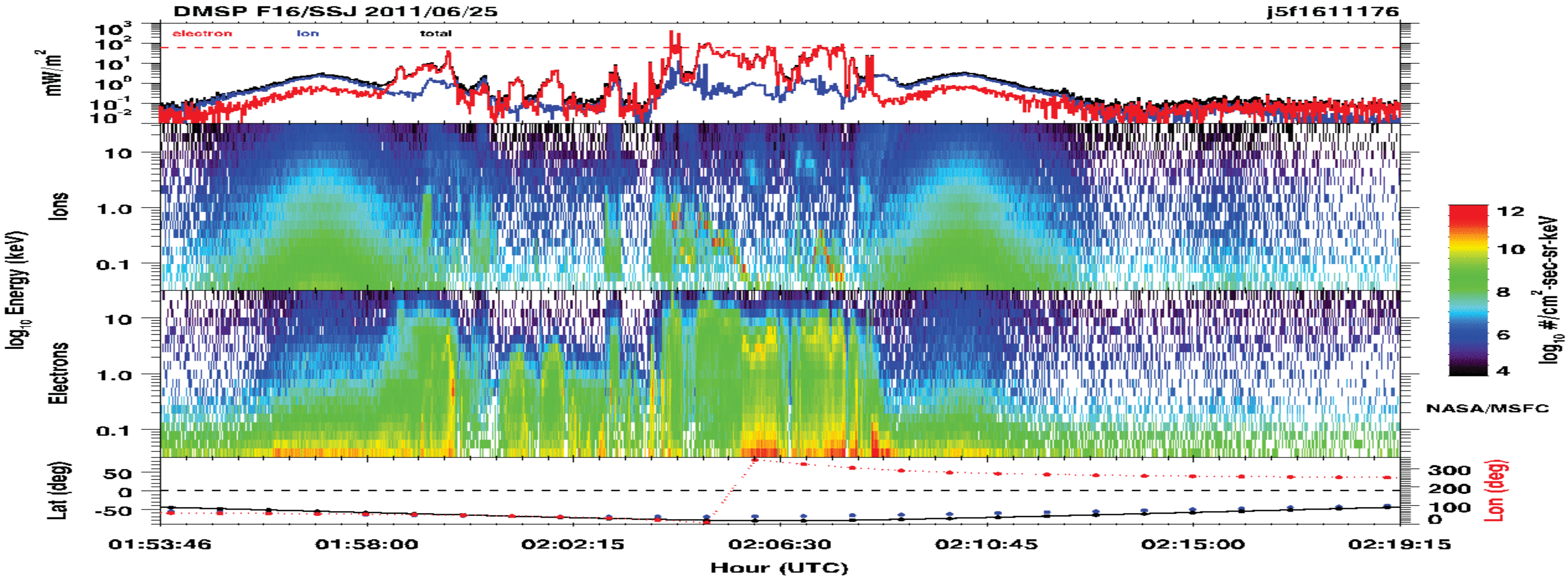


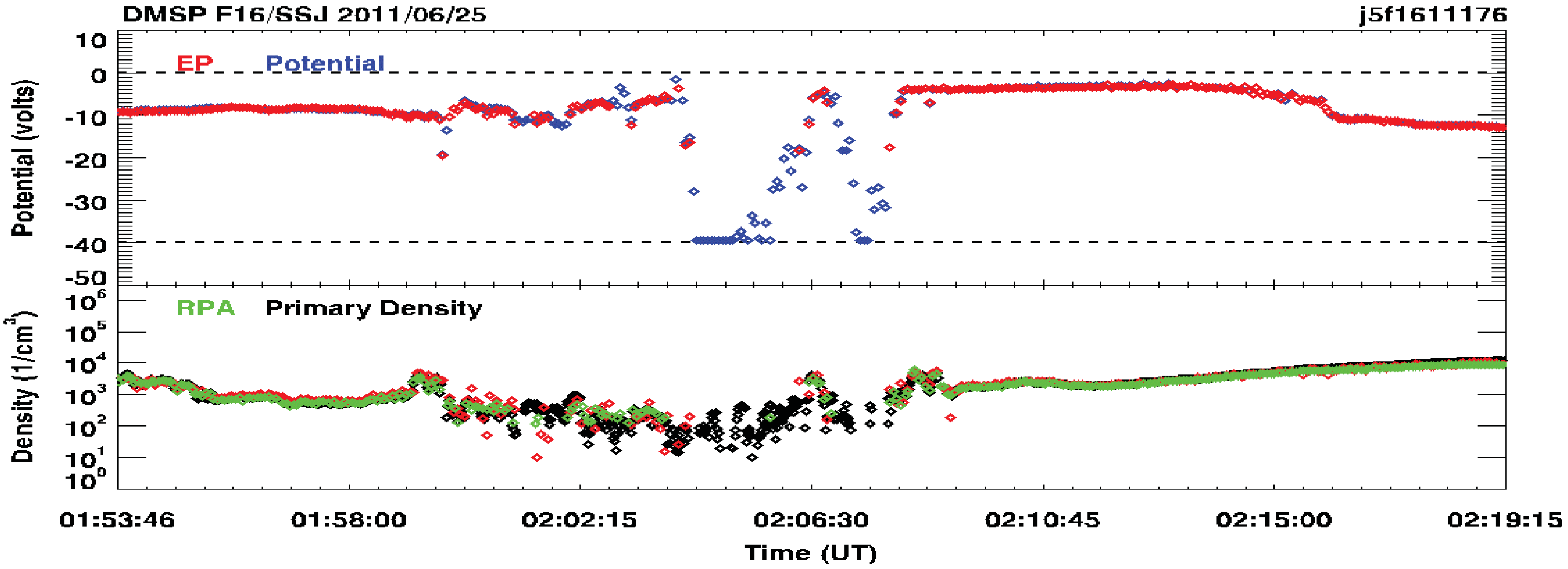


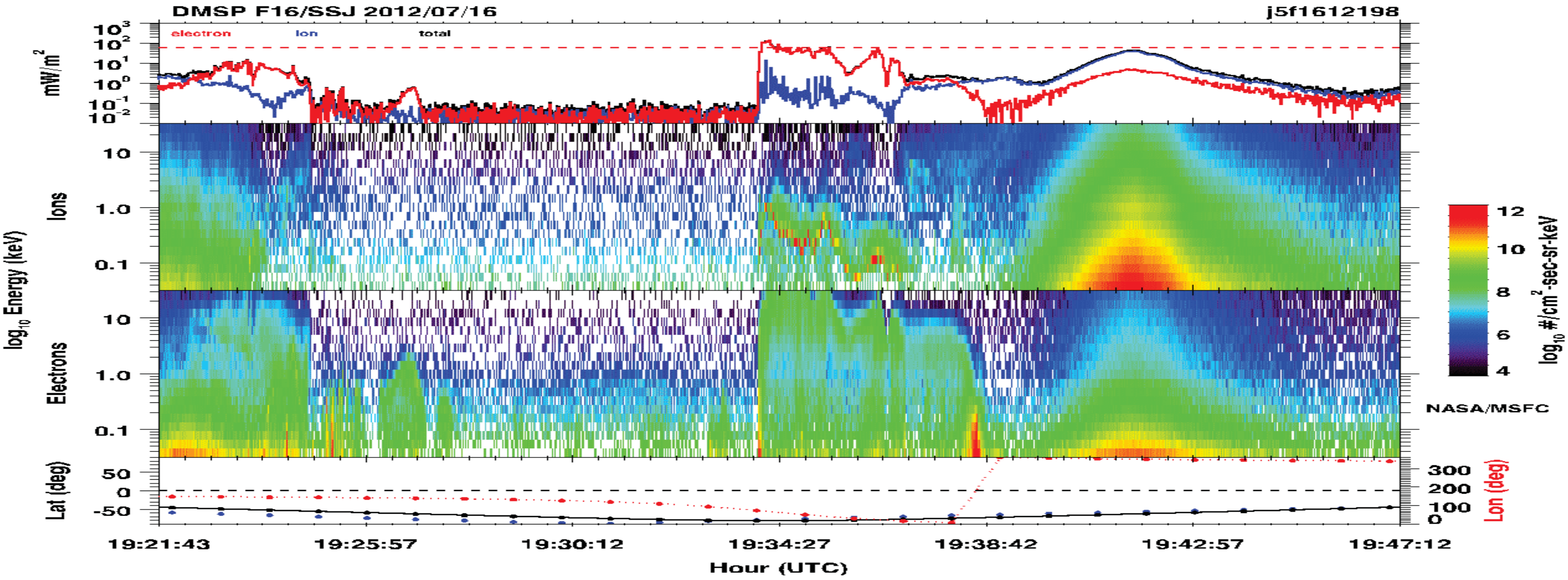
2011-06-25 01:53:46.0

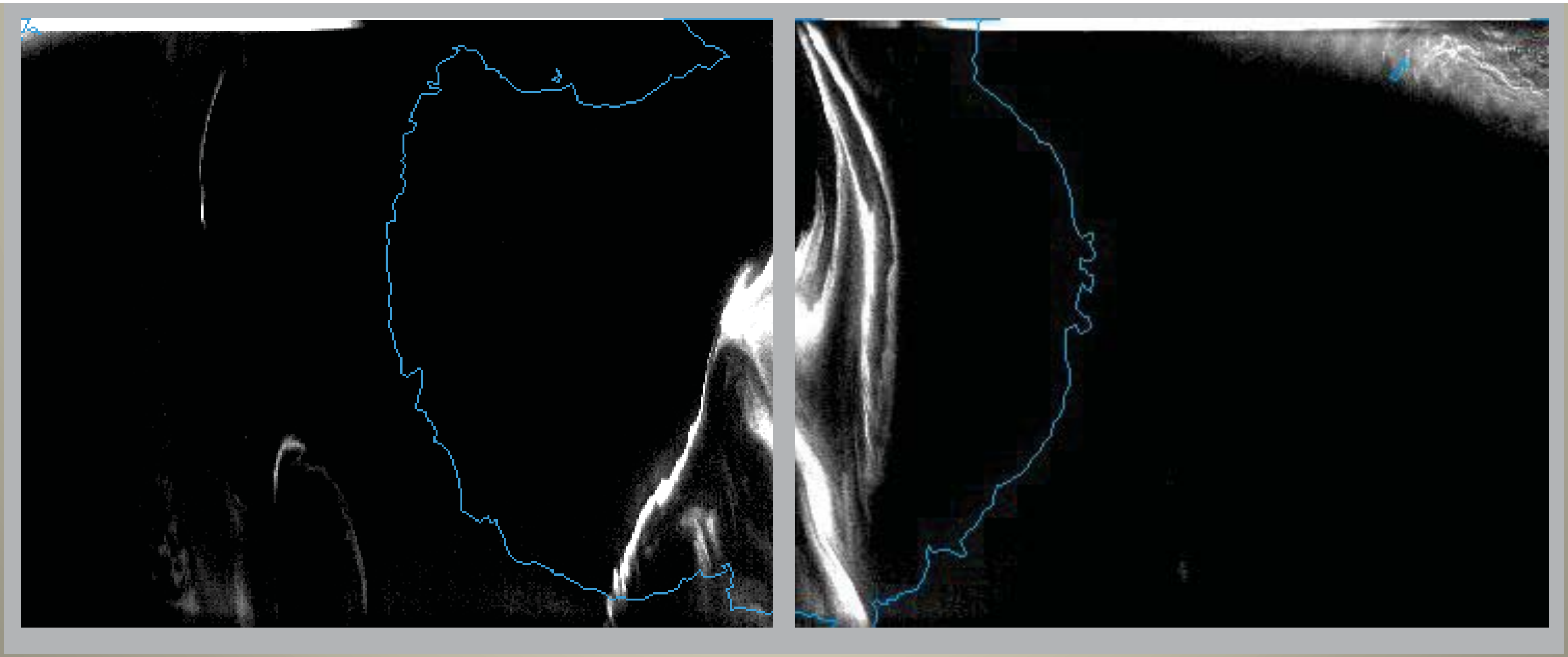
2011-06-25 02:06:30.0

2011-06-25 02:19:15.0


DMSP F16/SSJ 2011/06/25
j5f1611176
electron
ion
total
mW/m^2
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
log$_{10}$ Energy (keV)
Ions
Electrons
10
1.0
0.1
log$_{10}$ #/cm^2-sec-sr-keV
12
10
8
6
4
NASA/MSFC
Lat (deg)
50
0
-50
Lon (deg)
300
200
100
0
01:53:46
01:58:00
02:02:15
02:06:30
02:10:45
02:15:00
02:19:15
Hour (UTC)


DMSP F16/SSJ 2011/06/25
j5f1611176
EP
Potential
Potential (volts)
10
0
-10
-20
-30
-40
-50
RPA
Primary Density
Density (1/cm^3)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
01:53:46
01:58:00
02:02:15
02:06:30
02:10:45
02:15:00
02:19:15
Time (UT)

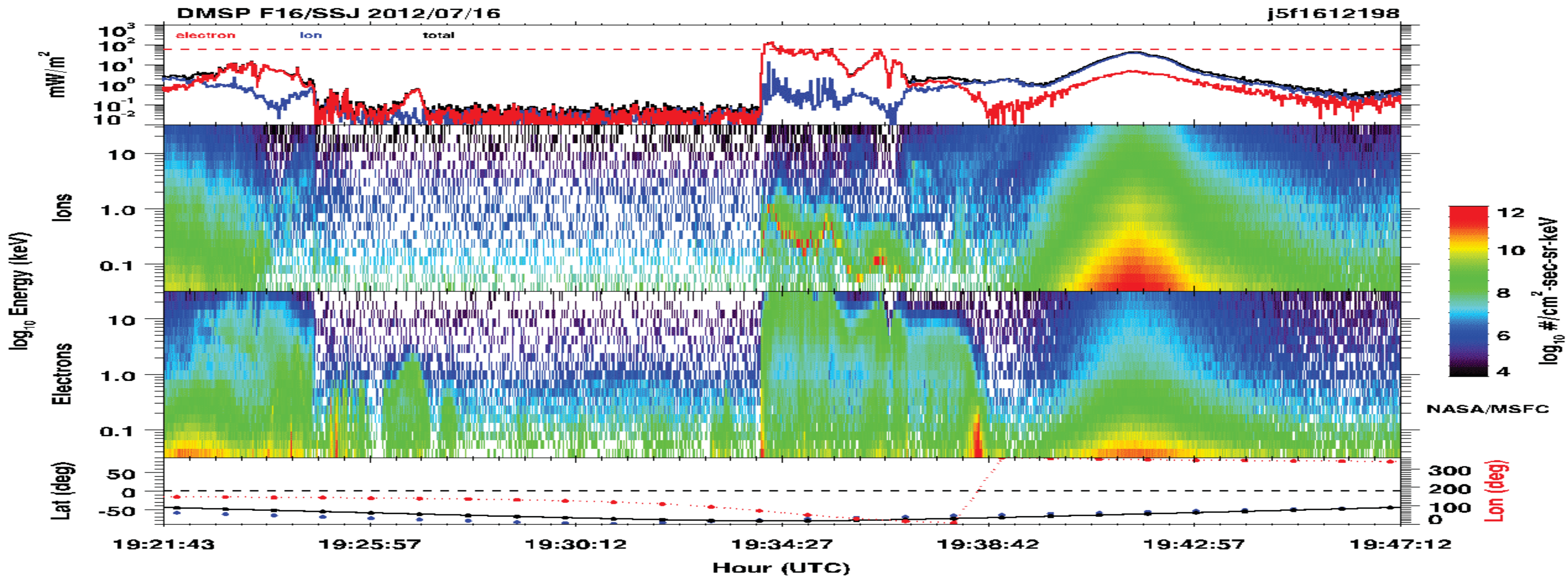


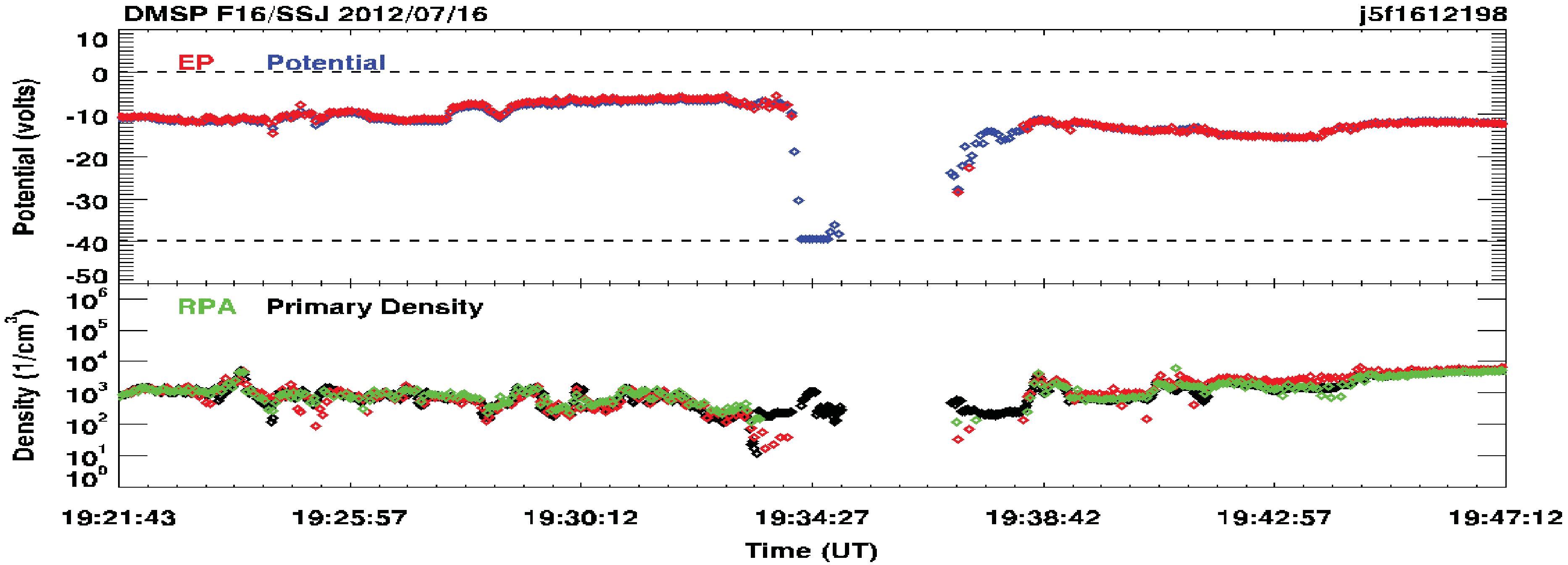


2012-07-16 19:21:43.0

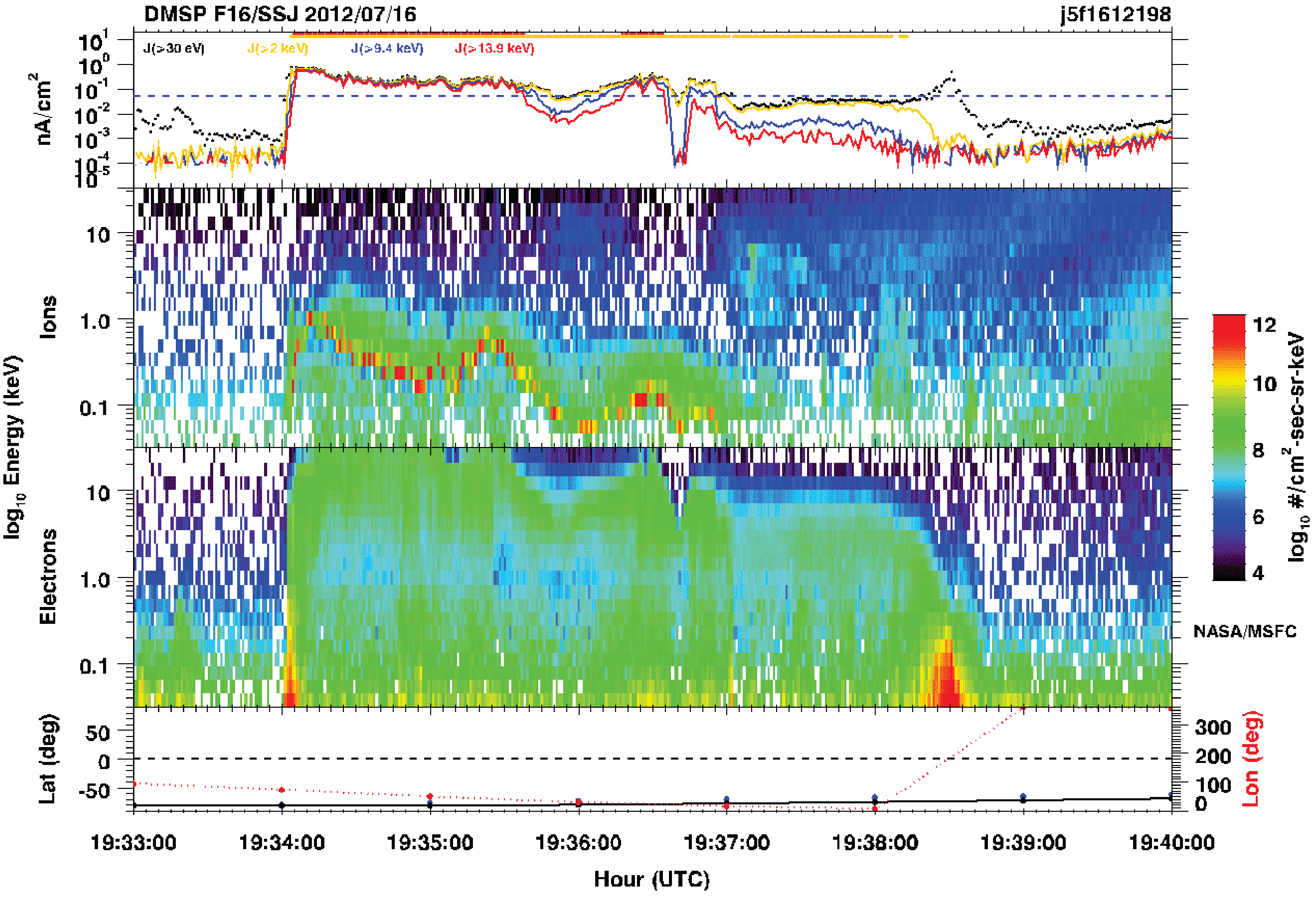
2012-07-16 19:34:27.0

2012-07-16 19:47:12.0

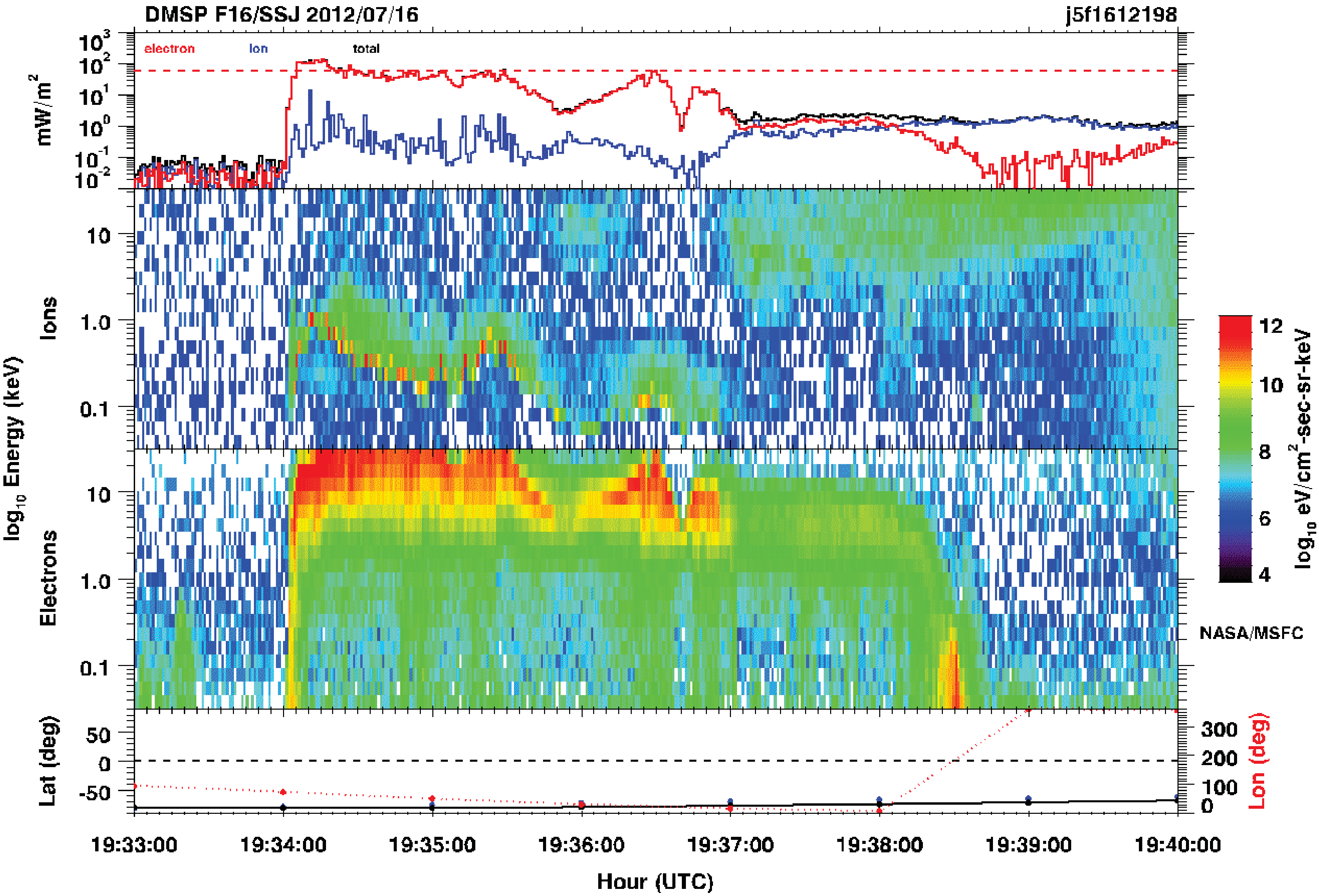

DMSP F16/SSJ 2012/07/16
j5f1612198
electron
ion
total
mW/m^2
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
log$_{10}$ Energy (keV)
Ions
Electrons
10
1.0
0.1
12
10
8
6
4
log$_{10}$ #/cm^2-sec-sr-keV
NASA/MSFC
Lat (deg)
50
0
-50
300
200
100
0
Lon (deg)
19:21:43
19:25:57
19:30:12
19:34:27
19:38:42
19:42:57
19:47:12
Hour (UTC)


DMSP F16/SSJ 2012/07/16
j5f1612198
EP
Potential
Potential (volts)
10
0
-10
-20
-30
-40
-50
RPA
Primary Density
Density (1/cm^3)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
19:21:43
19:25:57
19:30:12
19:34:27
19:38:42
19:42:57
19:47:12
Time (UT)

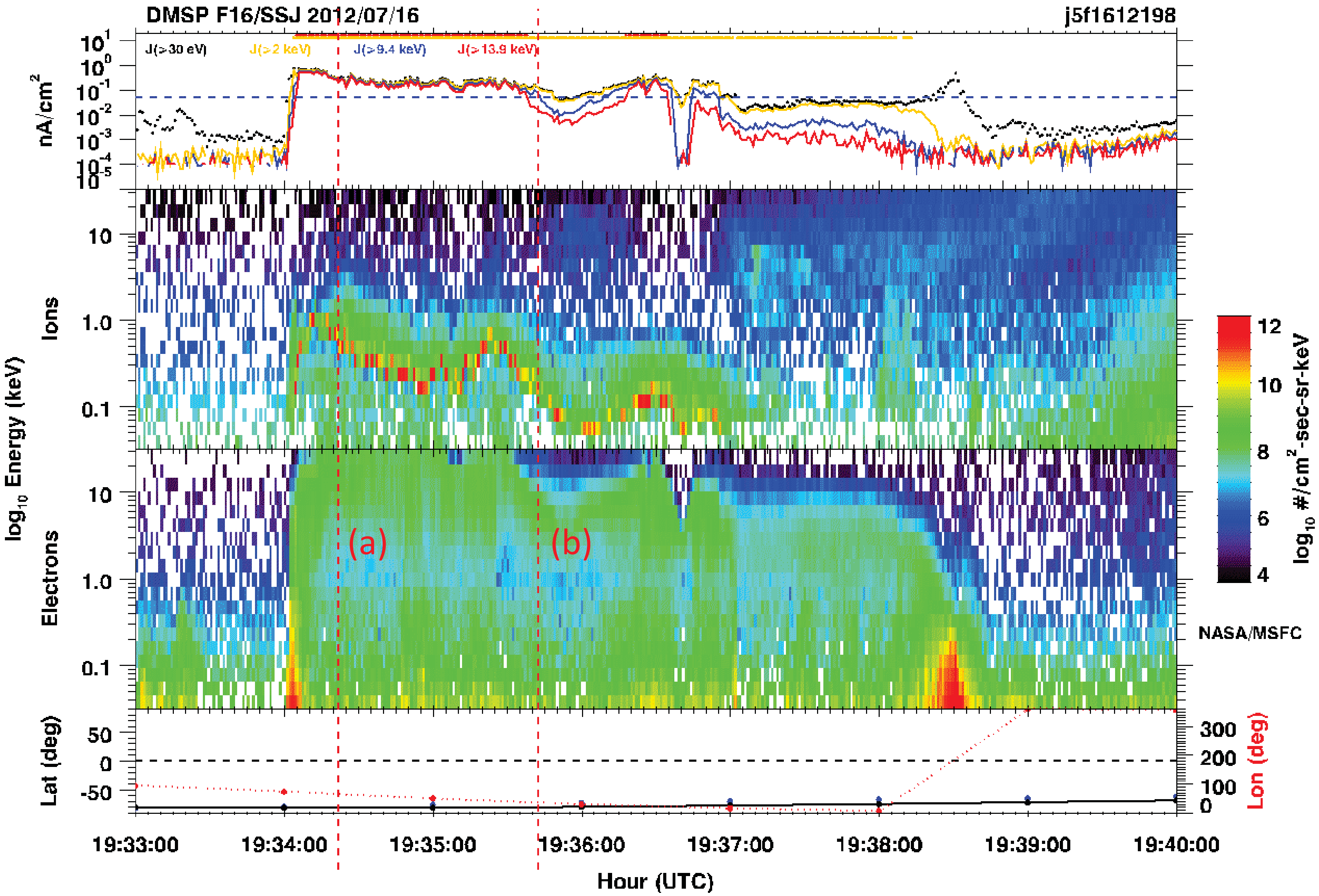
Event Detail: Number Flux and Current Density



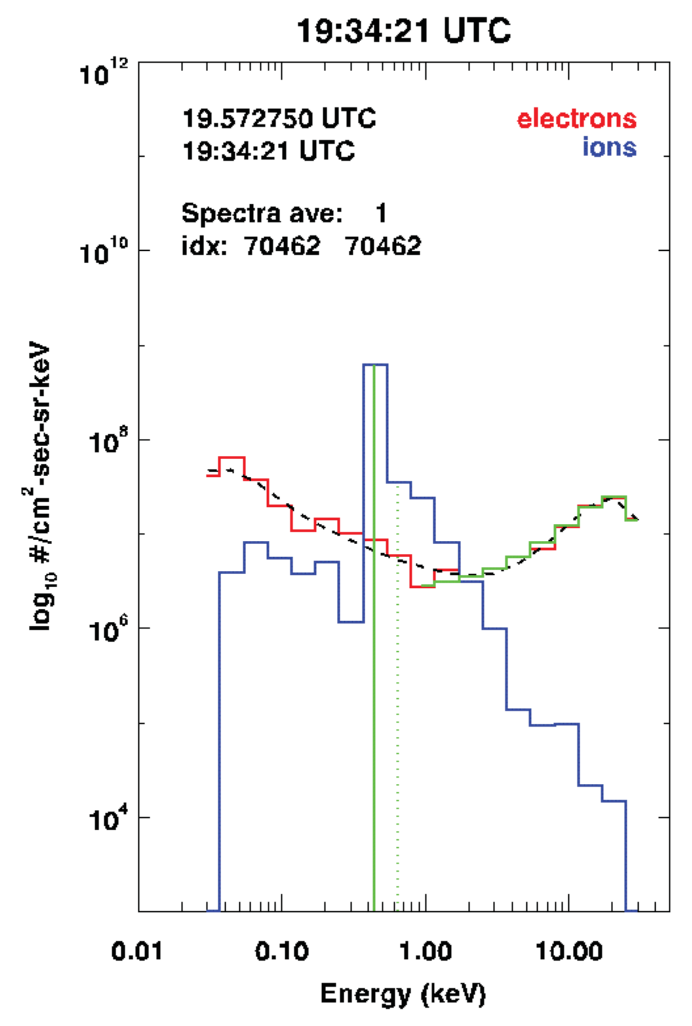
Event Detail: Energy Flux



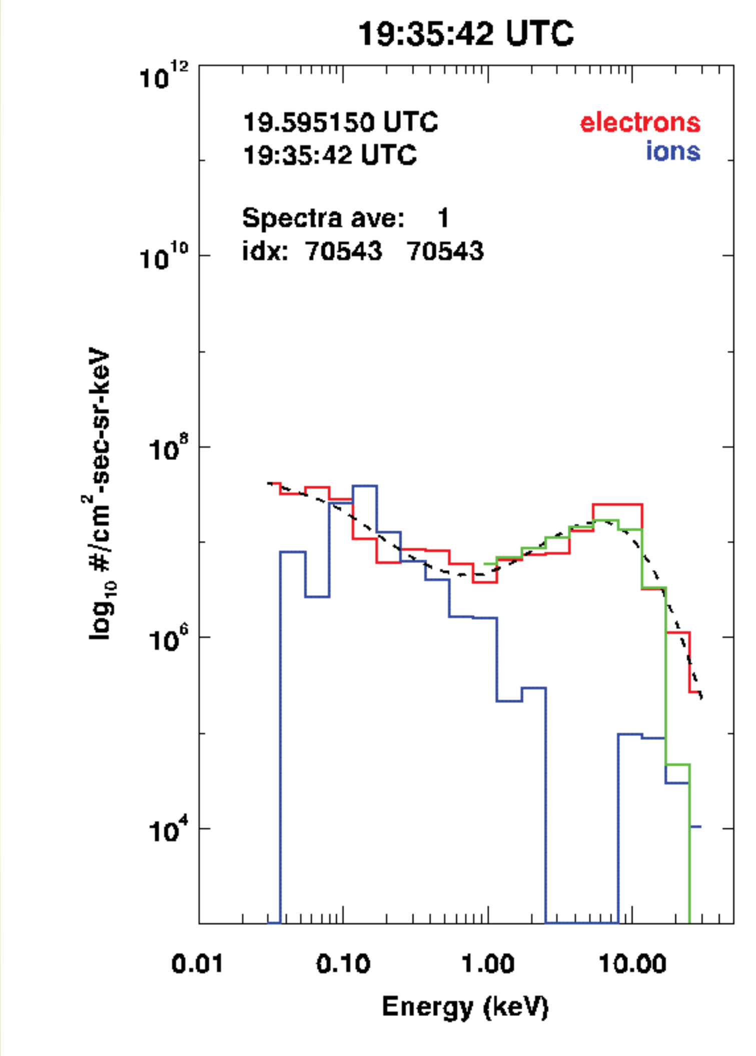
Individual Spectra



Individual Spectra



(a)



(b)

Fontheim Distribution

Ambient background

n=4.0e12 1/m3
Te=0.2 eV

Maxwellian

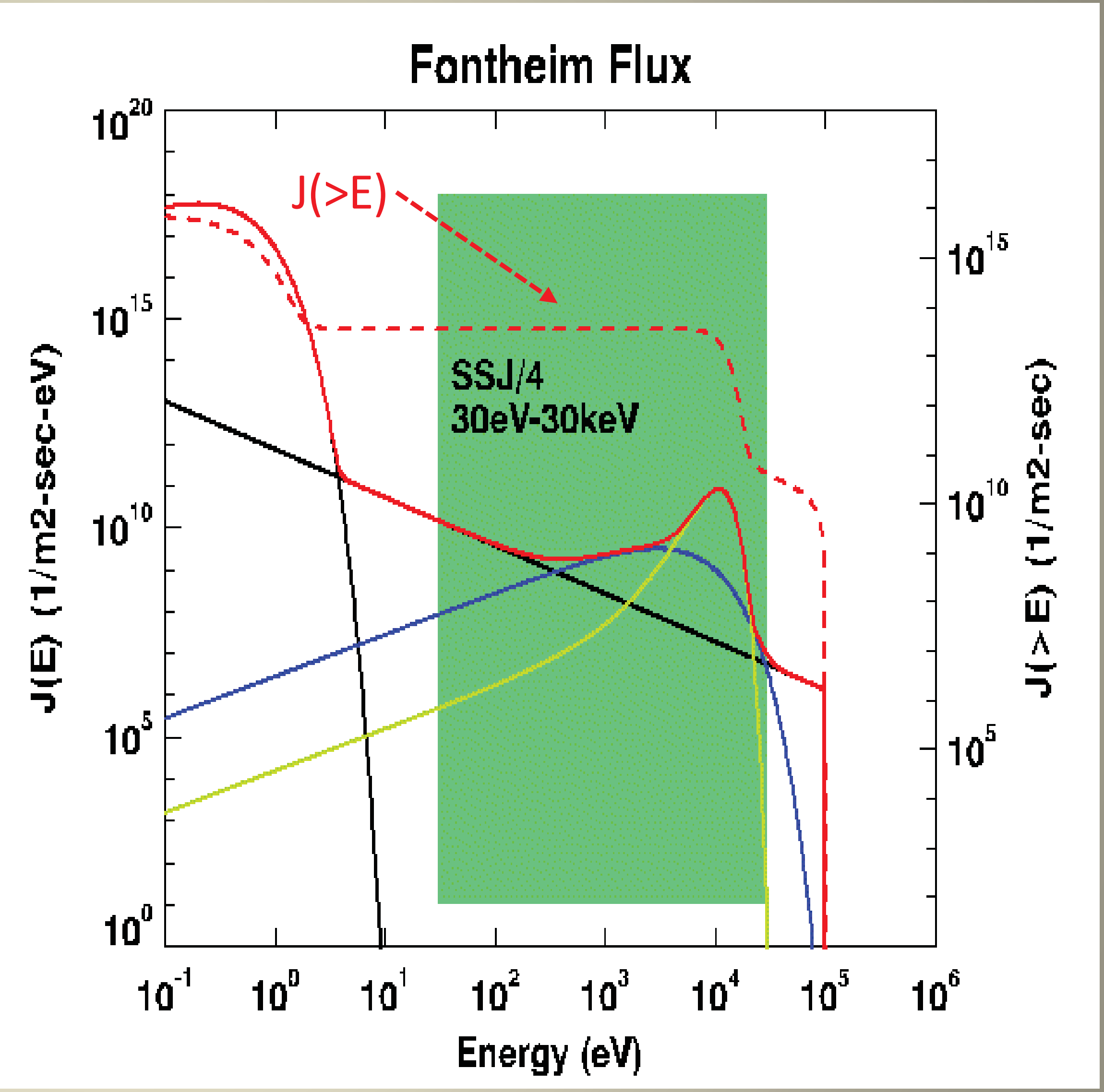
Jmax = 4.0e-6 A/m2
Te = 3.0e3 eV

Gaussian (beam)

Jgau =0.9e-4 A/m2
Egau = 10.0e3 eV beam energy
dgau = 4.0e3 eV beam width

Power Law

Jpwr = 3.0e-7 A/m2
alpha = 1.15 exponent
E1=50.0 eV, first energy
E2=1.0e5 eV, second energy



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

[Davis et al., 2011]

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
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Power Law

Jpwr = 3.0e-7 A/m^2
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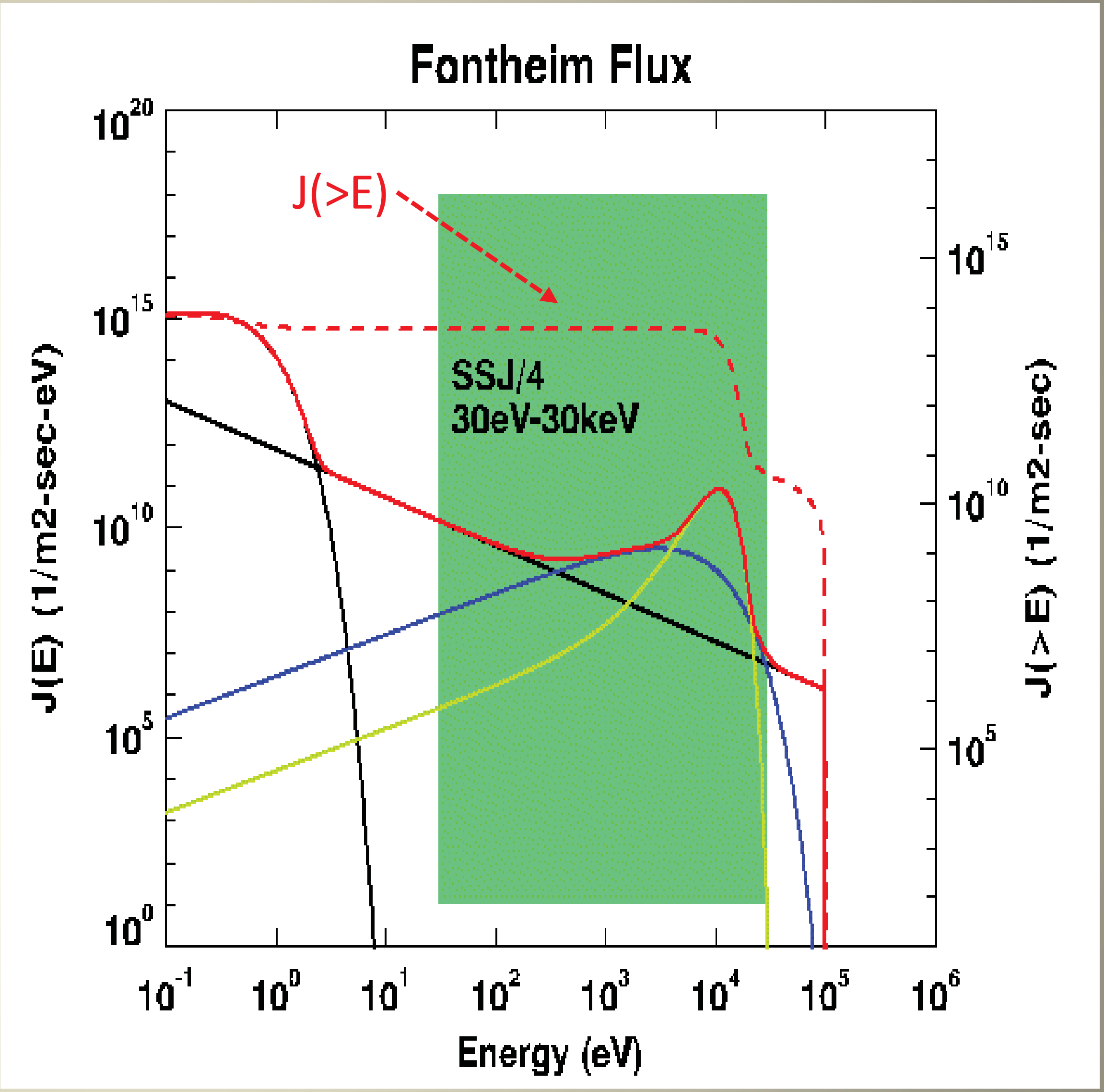
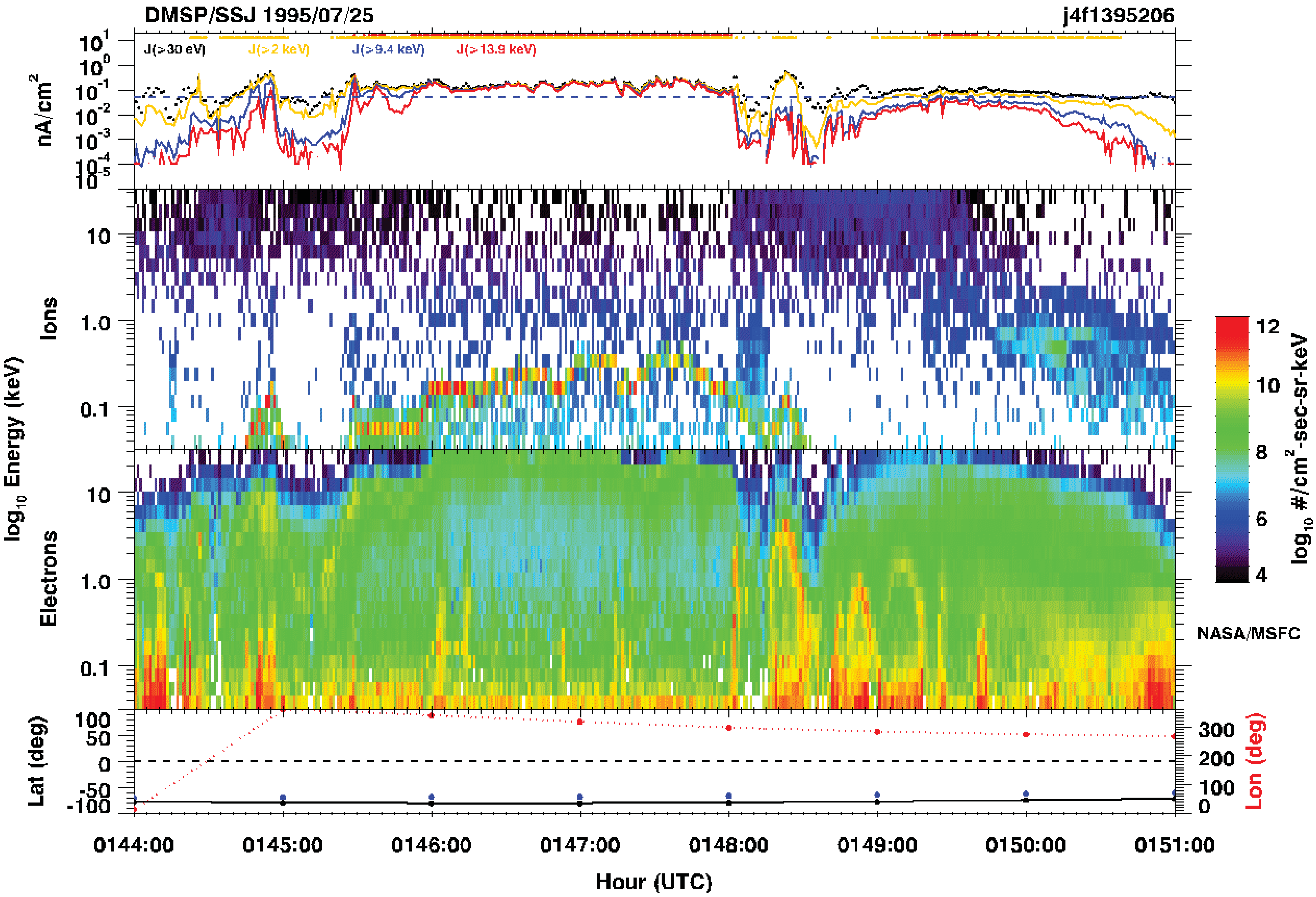


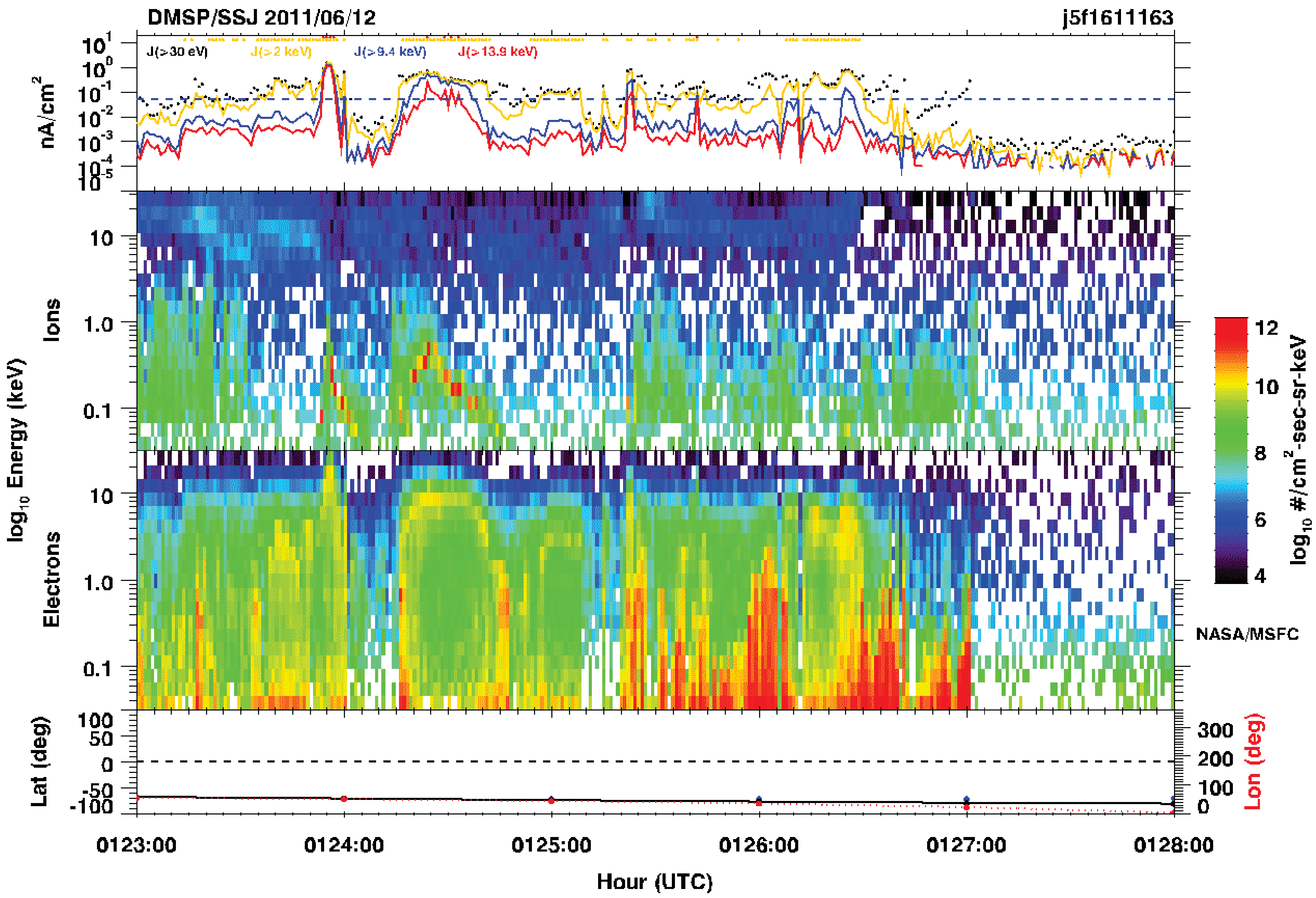
$$\mathrm{Flux}(E)=\sqrt{\frac{e}{2\pi\theta m_e}}\,\frac{E}{\theta}\,n\exp\left(-\frac{E}{\theta}\right)+\pi\zeta_{max}E\exp\left(-\frac{E}{\theta_{max}}\right)+\pi\zeta_{gauss}E\exp\left(-\left(\frac{E_{gauss}-E}{\Delta}\right)^2\right)+\pi\zeta_{power}E^{-\alpha}$$

[Davis et al., 2011]

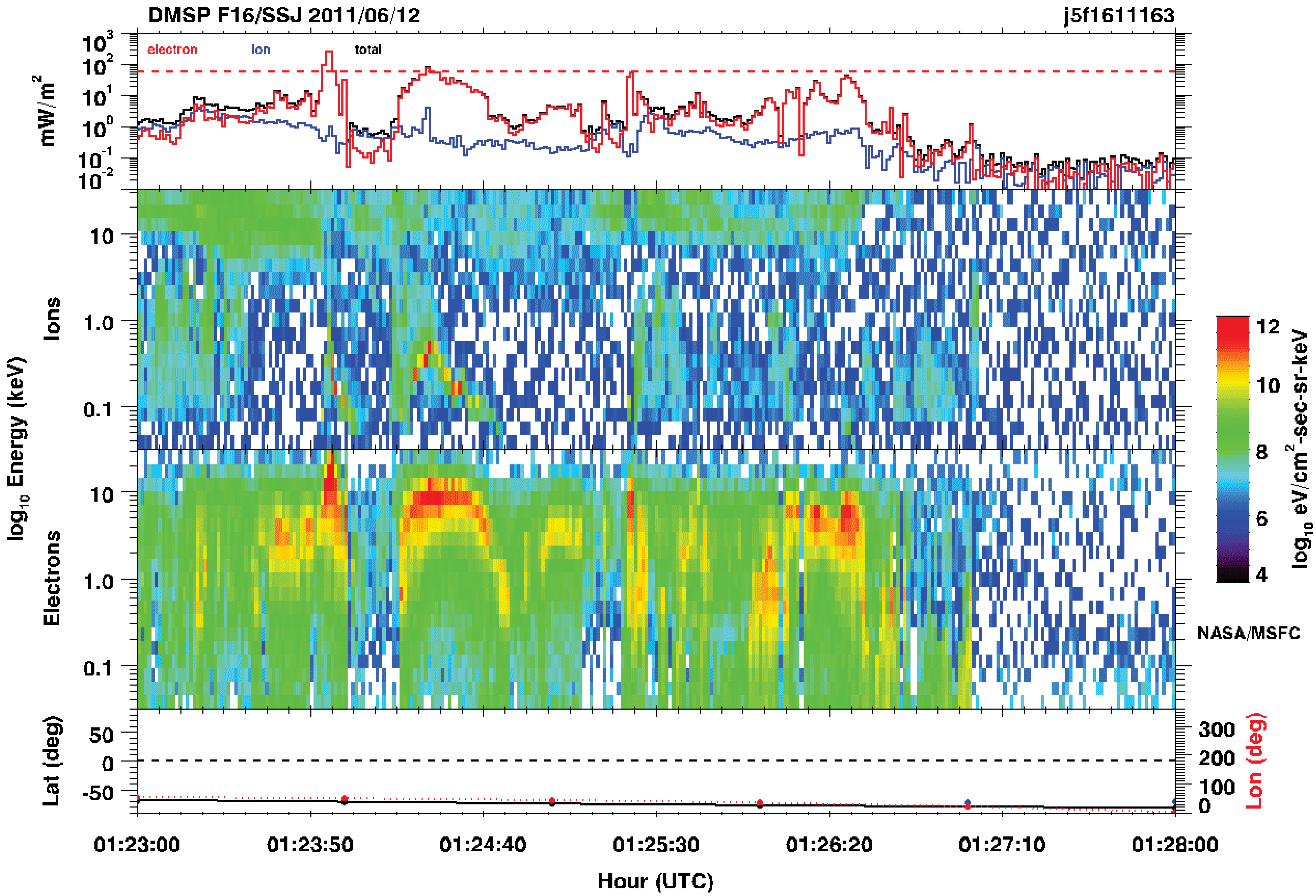
Long Duration Event



Inverted V, Broadband Aurora: N Flux

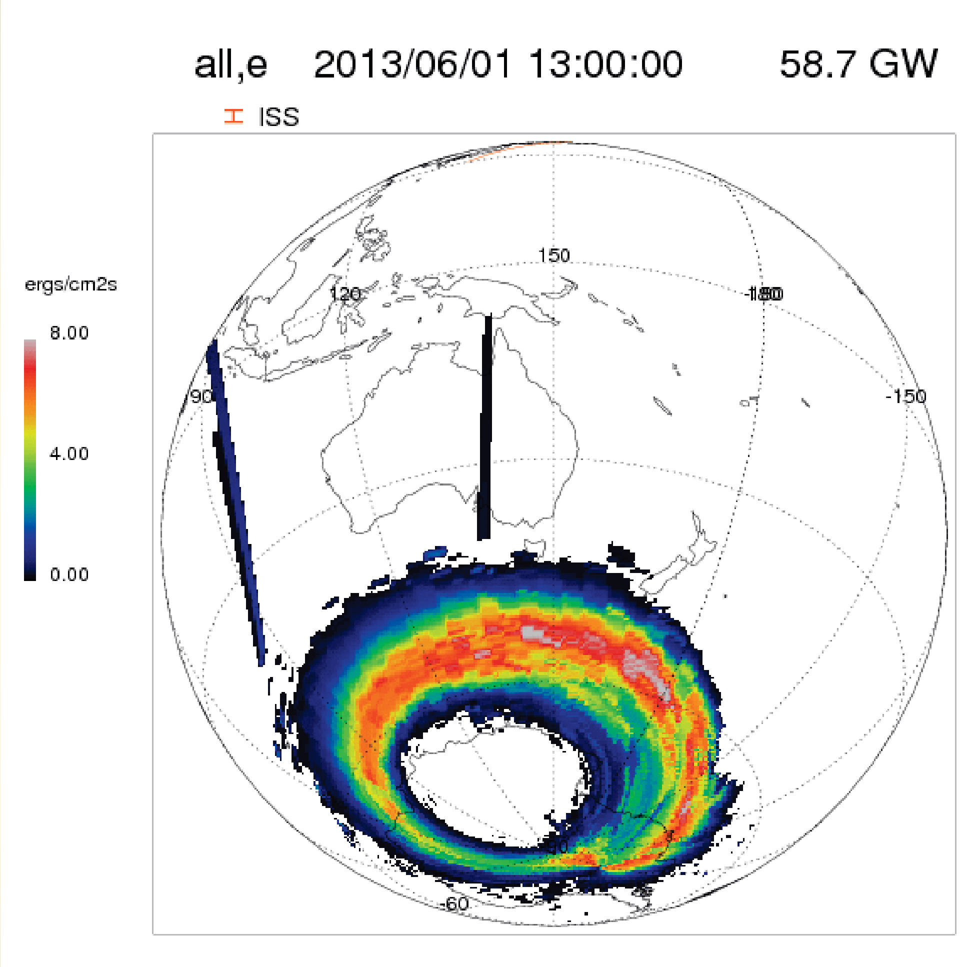


Inverted V, Broadband Aurora: E Flux

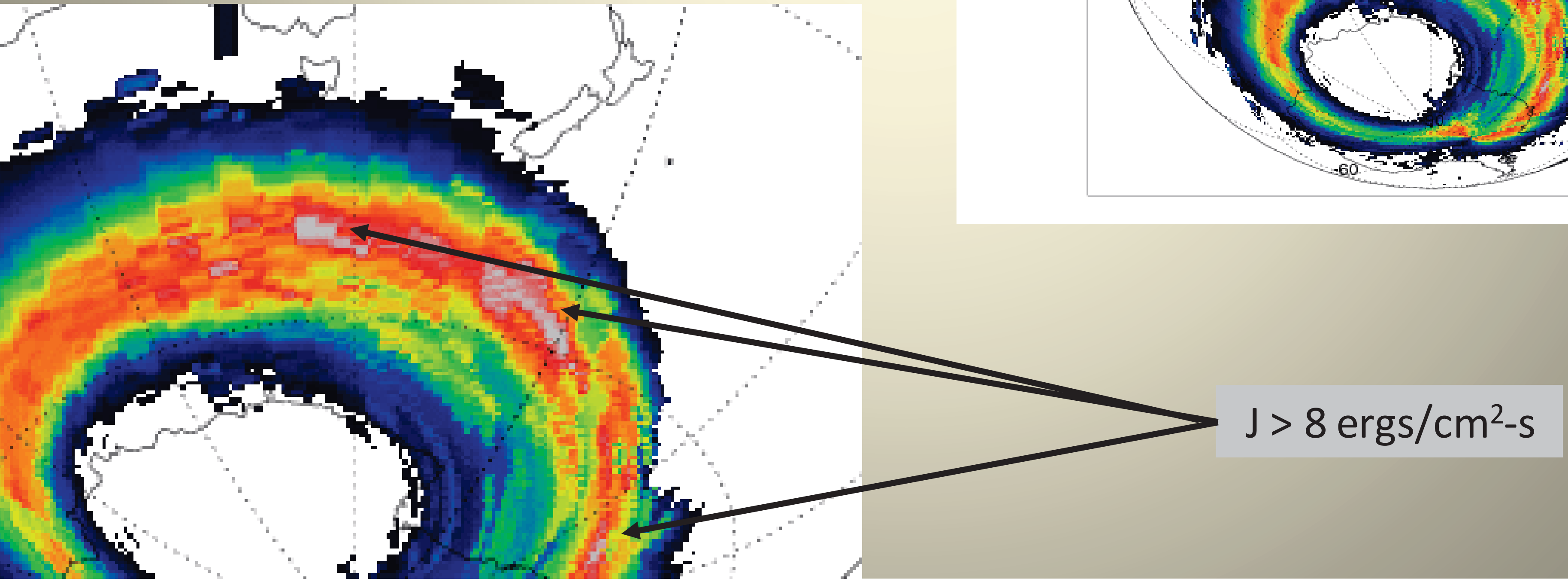


Aurora Models

- 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)



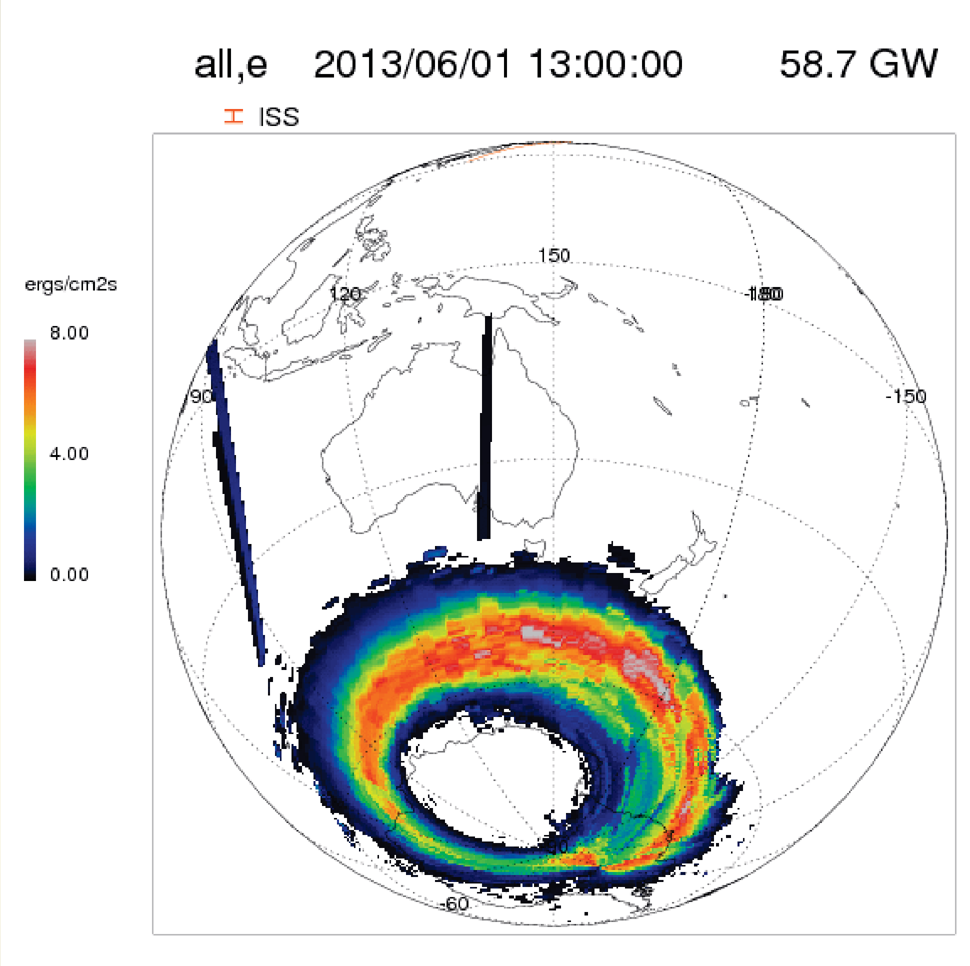
NASA CCMC



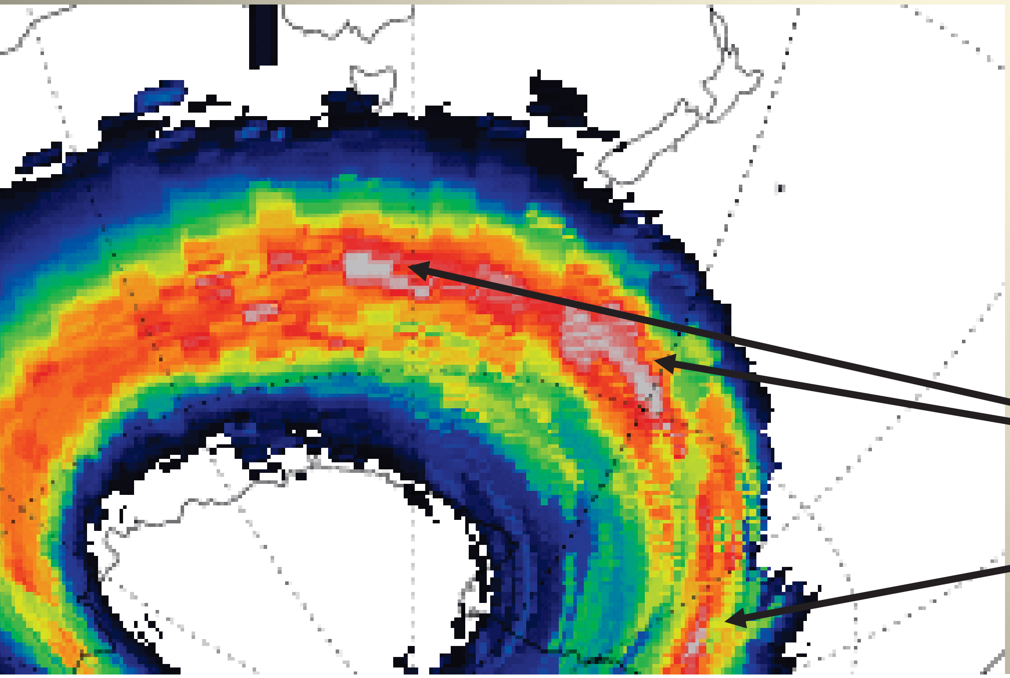
J > 8 ergs/cm^2-s

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

Summary

- Auroral charging is a function of both the space plasma charging environment and the characteristics of the spacecraft materials

- Space weather models need to be able to predict the inverted-v electron precipitation events and background plasma density in order to characterize auroral charging environments

- Surface charging models often use the Fontheim spectrum for characterizing the charging environment…..many parameters!!

- May be adequate to predict high total energy flux or, better yet, total energy flux <u>and</u> energy flux for E > ~10 keV electrons

Thank You

ISS image: 11 March 2012