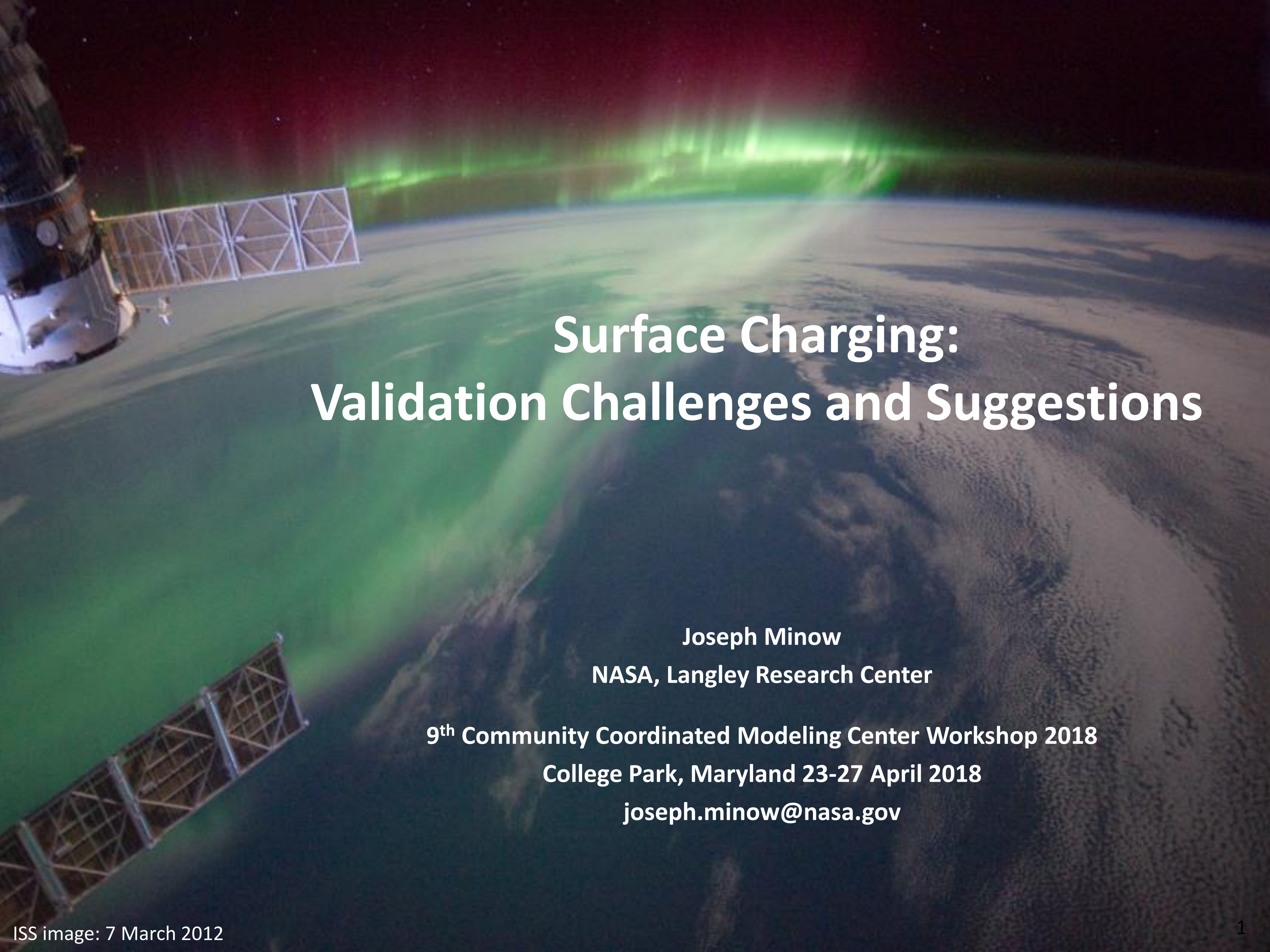

Surface Charging:
Validation Challenges and Suggestions

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Surface Charging Challenges

- Surface charging physics is a current balance phenomenon

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

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

$+I_i(V)$	**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**

- Surface charging threat environments

Environment	Extreme Potential
LEO auroral	-1 to -2 kV
LEO solar array	~90% of string voltage
GEO (GTO)	-10 kV to -20 kV

- Validating that a space weather model and charging code can be used to predict surface charging requires validating two models:
  - Does the space weather model correctly generate the relevant environments?
  - Does a spacecraft charging code generate the correct surface potential (or electric field) using space weather environment model inputs?

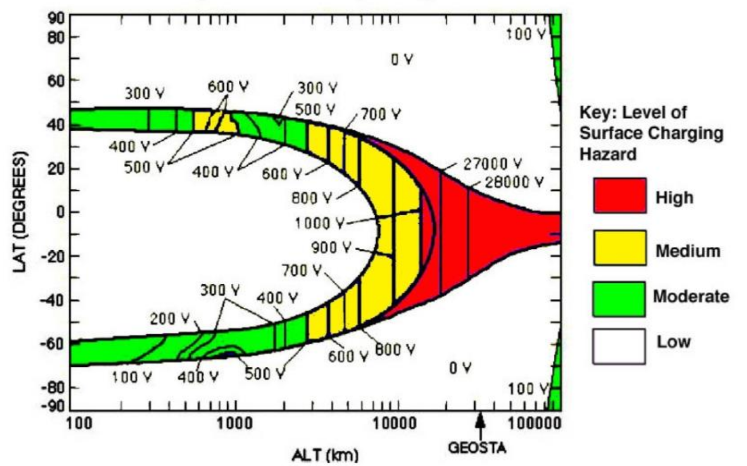
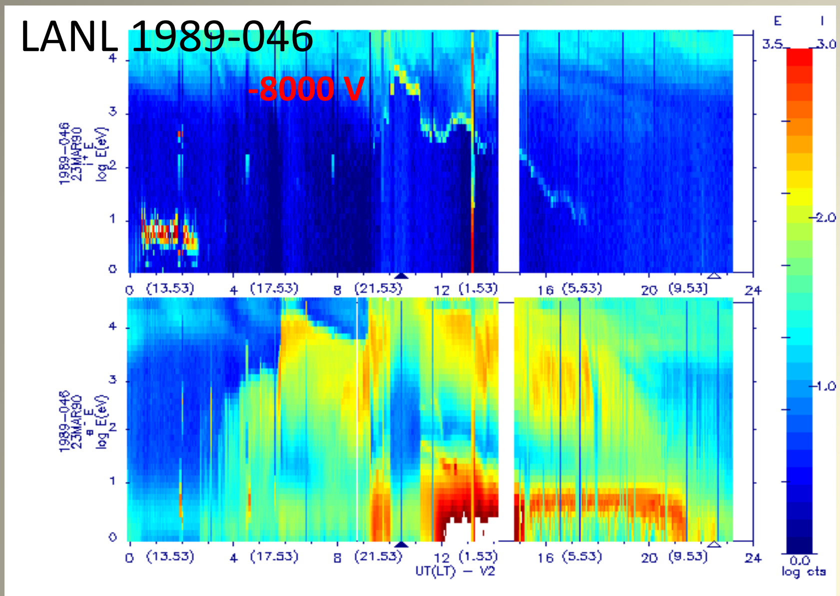


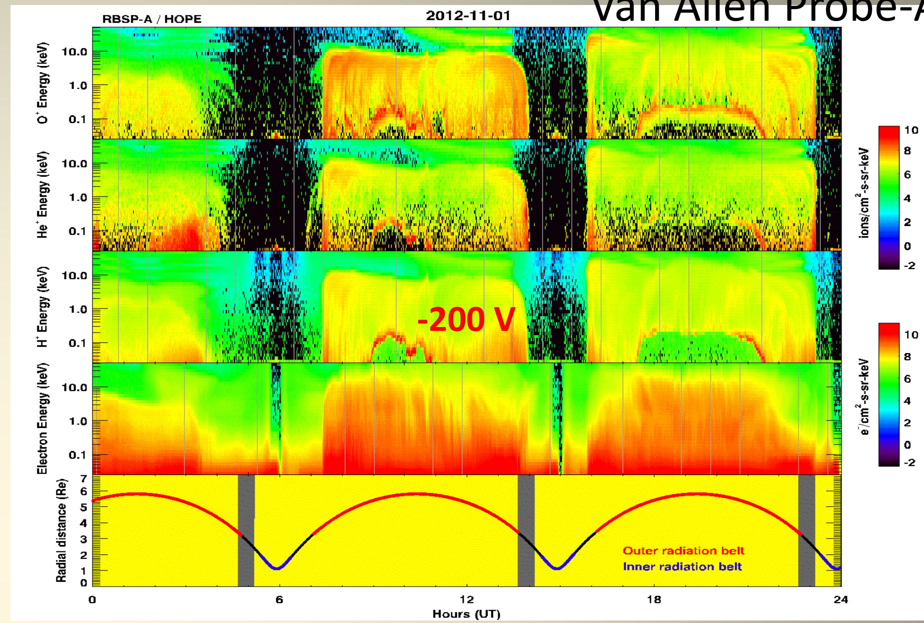
Figure 1—Earth Regimes of Concern for On-Orbit Surface Charging Hazards for Spacecraft Passing Through Indicated Latitude and Altitude (Evans and others (1989))

[NASA-HDBK-4002A, 2011]

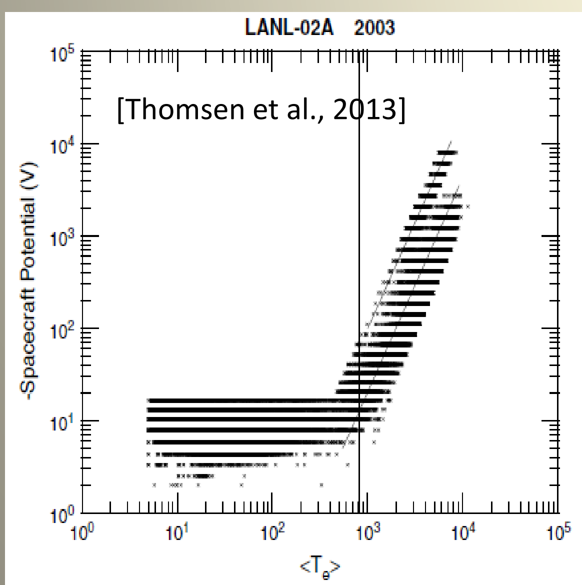
GEO (Outer Radiation Belt) Charging



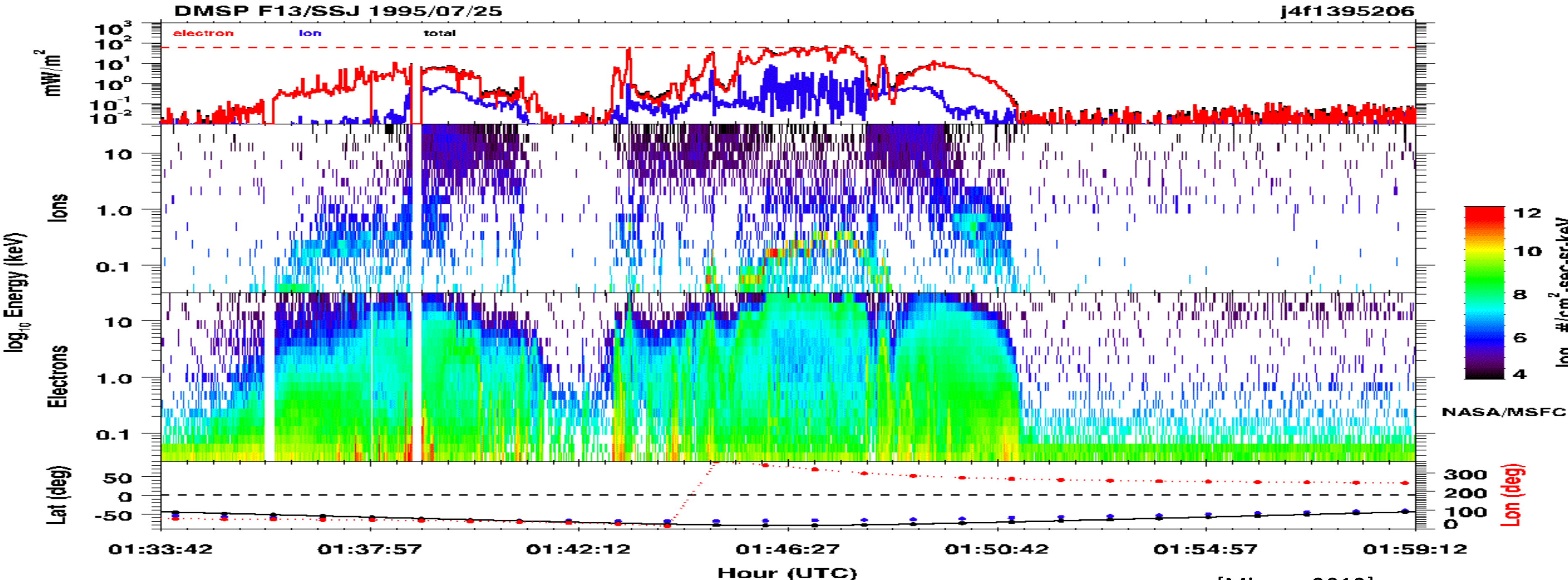
[https://www.mpa.lanl.gov]



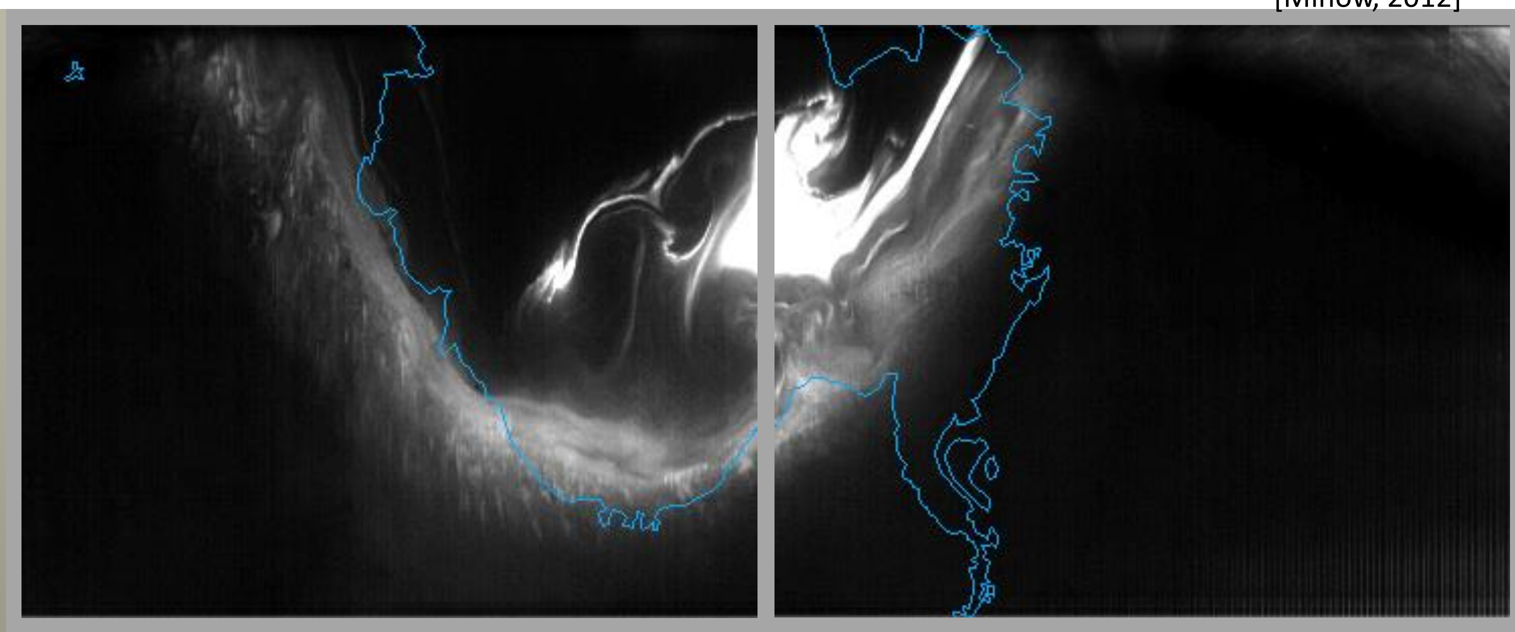
[Parker and Minow, 2014]



- GEO charging is driven by the hot thermal plasma during storm environments
- Space weather models need to predict the background
- Charging code inputs are typically Ne, Te parameters for a single or bi-maxwellian fits to electron and ion flux



[Minow, 2012]



1995-07-25 01:33:42.0

1995-07-25 01:46:27.0

1995-07-25 01:59:12.0

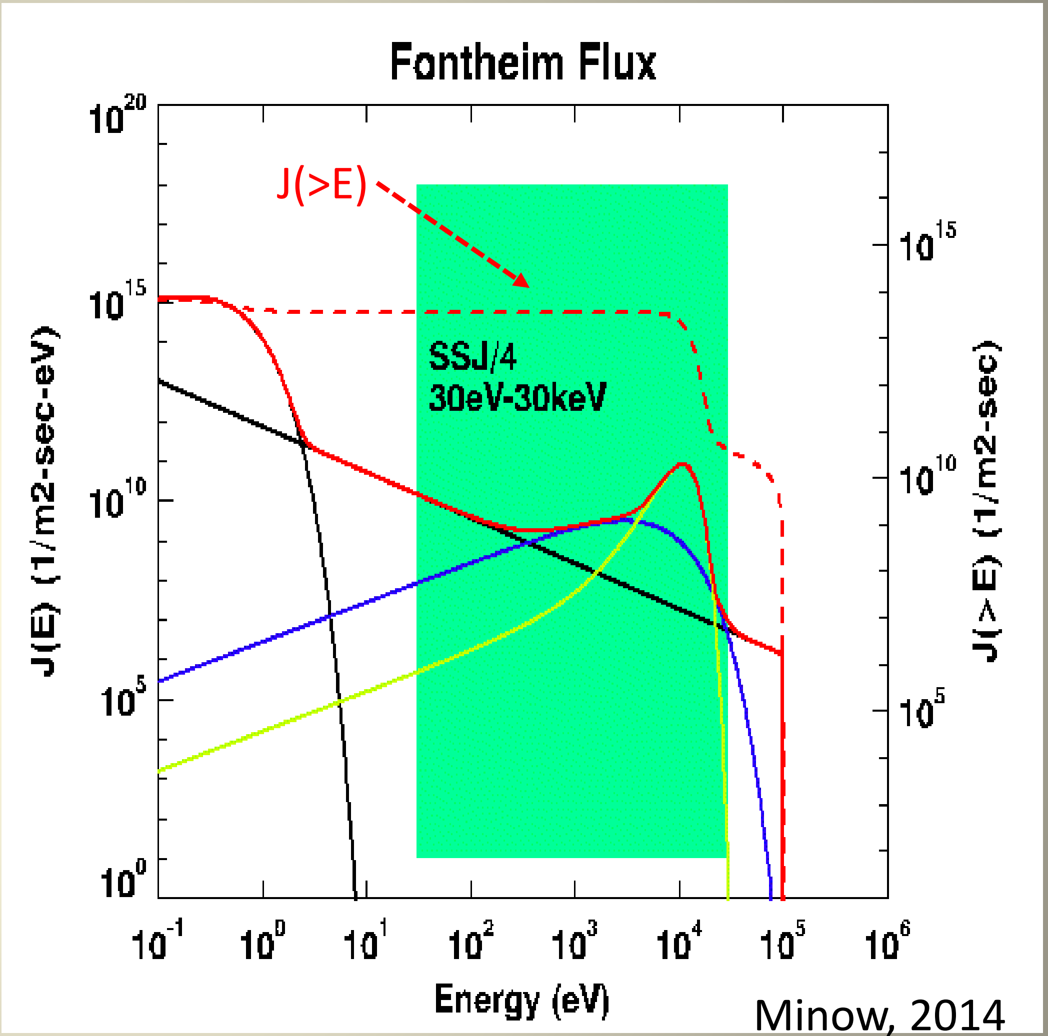
Fontheim Distribution

Ambient background
n=1.0e10 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]

Surface Charging Suggestions*

- Initial effort will focus on high priority GEO, MEO, GTO, and LEO polar environments where surface charging can exceed hundreds of volts
- User groups include spacecraft designers, operational situational awareness, anomaly investigations, and impact on science measurements
- Metrics (team is evaluating options):
  - Statistical evaluation using O'Brien "green anomalies" technique
  - Parameters used for inputs to charging models
    - GEO, MEO, GTO: Ne, Te, Ni, Ti or other
    - LEO polar (auroral): Ne, E_{beam}, ΔE_{beam}, and other Fontheim parameters
    - Flux spectra at different locations
- Environment models (initial focus):
  - Ovation – CCMC implementation
  - LANL model (Vania Jordanova)
  - IMPTAM (Natalia Ganjushkina)), run online in near-real time since 2013
  - CIMI (Natalia Buzulukova)
- Spacecraft charging models (secondary effort, but compare with $\Phi_{s/c}$)
  - Nascap
  - SPIS
  - SPENVIS, MUSCAT, and other small group charging codes

*Output from the surface charging sessions at the ICCMC-LWS, Cape Canaveral, FL 3-7 April 2017

Metrics (I): Surface Charging

- The traditional ones
  - RMSE root mean square error
  - Ratio of maximum amplitude(flux)
  - Prediction efficiency

- Above a certain threshold (yes/no prediction)
  - >10 keV flux exceeds 1.5e7 (1/cm^2/sec/ster) (surface charging threshold)
  - Whether a model prediction predicts a surface charging event during a certain interval with the defined threshold
  - Generation of a contingency table of hit (H), miss (M), false positive (F), and correct negative (N) model predictions
  - Heidke Skill Score (for a large enough surface charging events)

Metrics (II): Surface Charging

- New ones using log ratio (Morley et al., 2018) satisfying the four attributes (see below)
  The median symmetric accuracy

  $$\varsigma = 100(\exp(M\ (|log_e(Q_i)|)\ ) - 1)$$

  where $Q_i = \frac{y_i}{x_i}$: ratio of predicted versus observed, y_i: model, x_i: observation
  M: median value
  The Symmetric Signed Percentage Bias (SSPB):

  SSPB= $100\ sgn\ \left(M\ \left(log_e(Q_i)\right)\right)(\exp\left(\left|M\left(log_e(Q_i)\right)\right|\right) - 1)$

  Sgn: signum function; M: median value

(1) The metrics must be meaningful for data that cover orders of magnitude,
(2) underprediction and overprediction by the same factor should be penalized equally,
(3) the metrics should be easy to interpret, and
(4) the metrics should be robust to the presence of outliers and bad data.

ISS image: 7 March 2012