Internal Charging

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NASA/MSFC

7th CCMC Workshop

31 March – 4 April 2014

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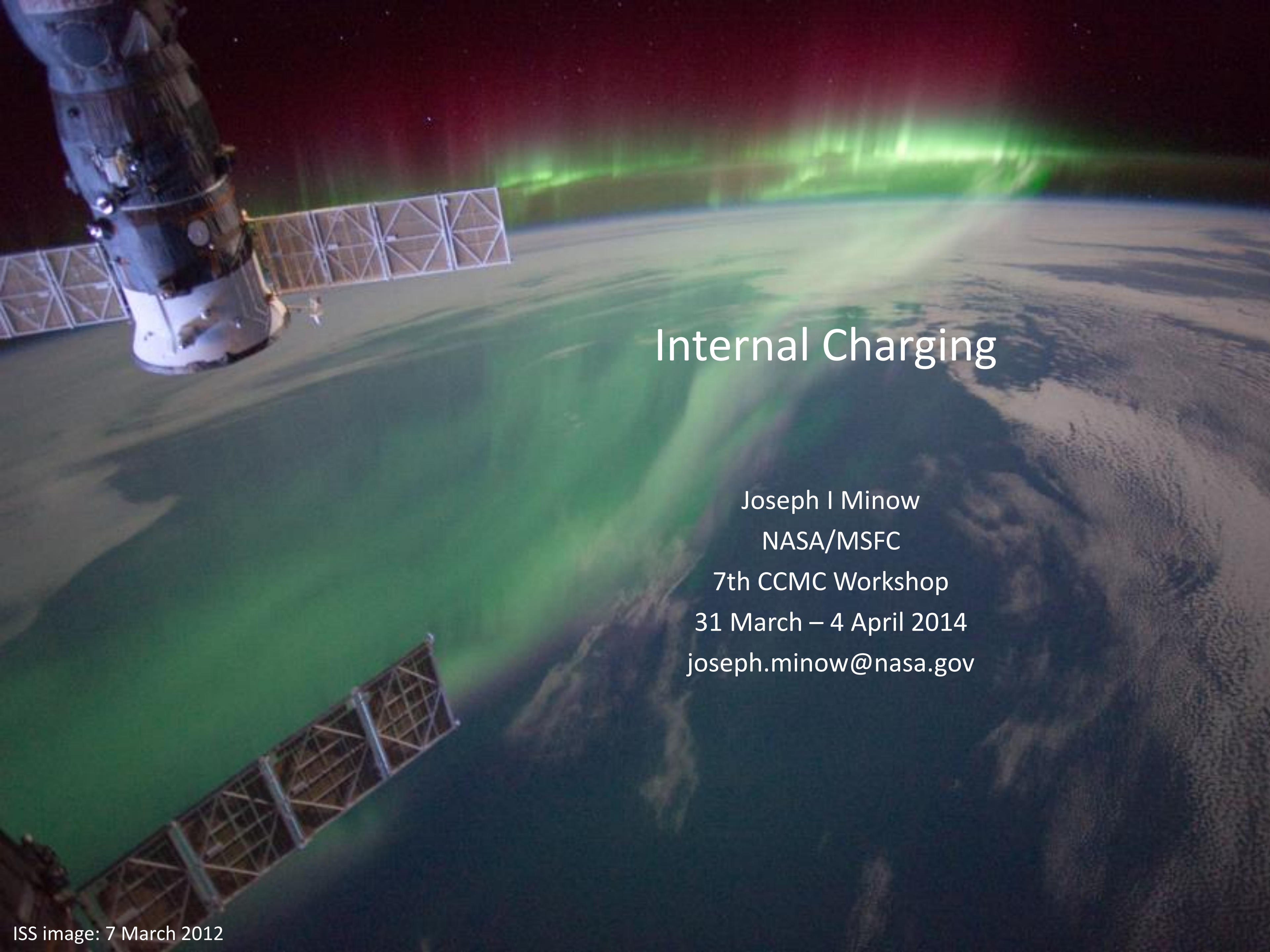


ISS image: 7 March 2012

Introduction

NASA Goddard Space Flight Center, Space Weather Research Center (SWRC)
Message Type: Space Weather Alert
Message Issue Date: 2013-07-12T11:35:00Z
Message ID: 20130712-AL-001

Summary:

Significantly elevated energetic electron fluxes in the Earth's outer radiation belt. GOES 13 "greater than 0.8 MeV" integral electron flux is above 10^5 pfu starting at 2013-07-12T11:00Z.

Spacecraft at GEO, MEO and other orbits passing through or in the vicinity of the Earth's outer radiation belt can be impacted.

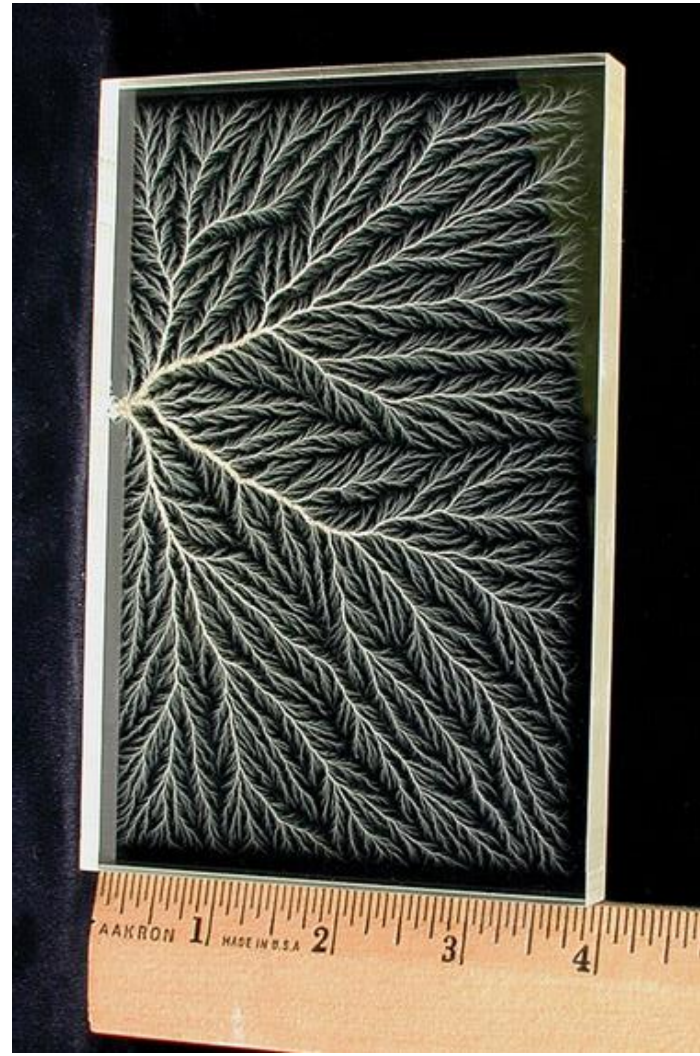
Activity ID: 2013-07-12T11:00:00-RBE-001.

Outline

- Internal charging
- MeV electron fluence threat thresholds
- NUMIT internal charging model
- Real time GEO internal charging tool
- LEO internal charging tool

Internal (Deep Dielectric) Charging

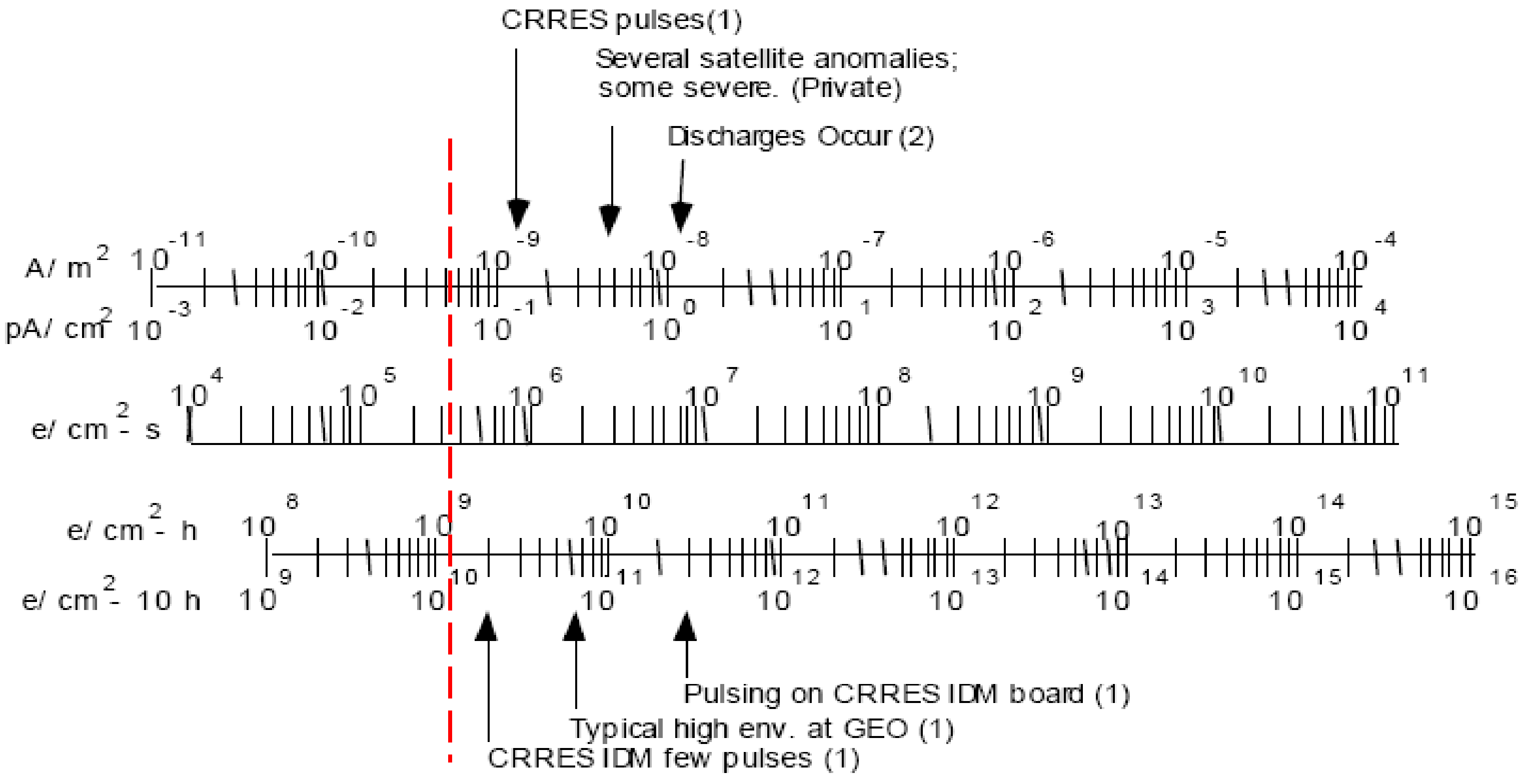
- High energy (>100 keV) electrons penetrate spacecraft walls and accumulate in dielectrics or isolated conductors
- Threat environment is energetic electrons with sufficient flux to charge circuit boards, cable insulation, and ungrounded metal faster than charge can dissipate
- Accumulating charge density generates electric fields in excess of material breakdown strength resulting in electrostatic discharge
- System impact is material damage, discharge currents inside of spacecraft Faraday cage on or near critical circuitry, and RF noise



PMMA (acrylic) charged by ~2 to 5 MeV electrons

MeV Electron Threat Fluence Thresholds

- NASA-HBK-4002A: ~MeV electron flux ≥ 9×10^4 e/cm2-sec-sr (10^10 e/cm2 in 10 hours)
- CCMC/SWRC: > 0.8 MeV electron flux > 1×10^5 e/cm2-sec-sr
- NOAA/SWPC >2 MeV electron flux > 1×10^3 e/cm2-sec-sr



NUMIT Model for EVA Suit Charging

- **NUMIT computes charge deposition, electric field as function of depth in insulating materials due to radiation charging by electrons**
- **Five material layers parameterized by electrical resistivity, radiation induced conductivity parameters, dielectric constant**

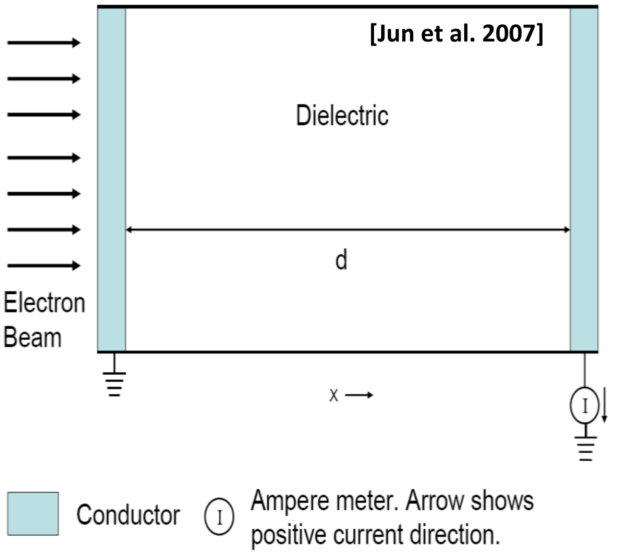


Table 1-2 NUMIT Model, Existing Suit

Layer	Z_{eff}	A_{eff}	Density (g/cm3)	Vol. Resis. (S/m)	κ	RIC (S/m)	RIC Exp	Depth (cm)
								0
1	8.25	17.19	0.429	1.00E+16	2	1.00E+14	0.7	0.114
2	5.484	10.008	1.225	1.00E+12	2	1.00E+14	0.7	0.137
3	6.24	11.99	0.752	1.00E+17	2	1.00E+14	0.7	0.165
4	6.083	11.291	0.501	1.00E+15	4	1.00E+14	0.7	0.193
5	5.484	10.008	3.031	1.00E+12	2	1.00E+14	0.7	0.244
Total								
Total	31.541	60.487	5.938					
Average	6.3082	12.0974	1.1876					
Wt Ave	6.0847	11.555	2.0485					

Layer Number	Material
---	space (outside of suit)
1	**Teflon/Nomex/Kevlar**
2	**Neoprene coated Nylon**
3	**Dacron polyester**
4	**Urethane coated Nylon**
5	**Nylon chiffon, Nylon Spandex, water cooling tubes**
---	skin (inside suit)

$$\nabla \bullet D = \rho$$

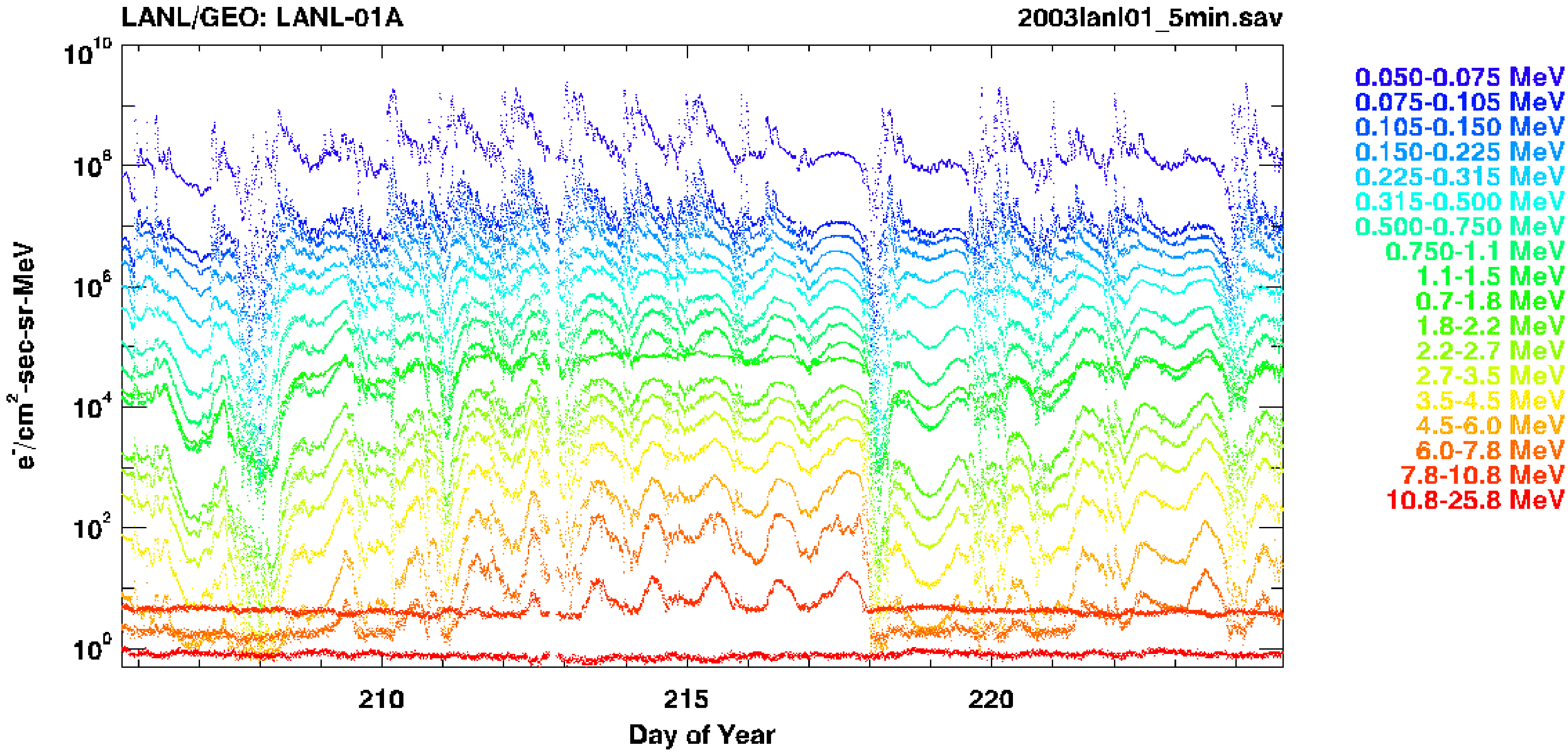
$$D = \varepsilon E, \quad \varepsilon = \kappa \varepsilon_0$$

$$\frac{\partial \rho}{\partial t} = -\nabla \bullet J$$

$$J = J_R + J_C = J_R + \sigma E$$
$$= J_R + \left[\sigma_{dark} + \sigma_{radiation}\right] E$$

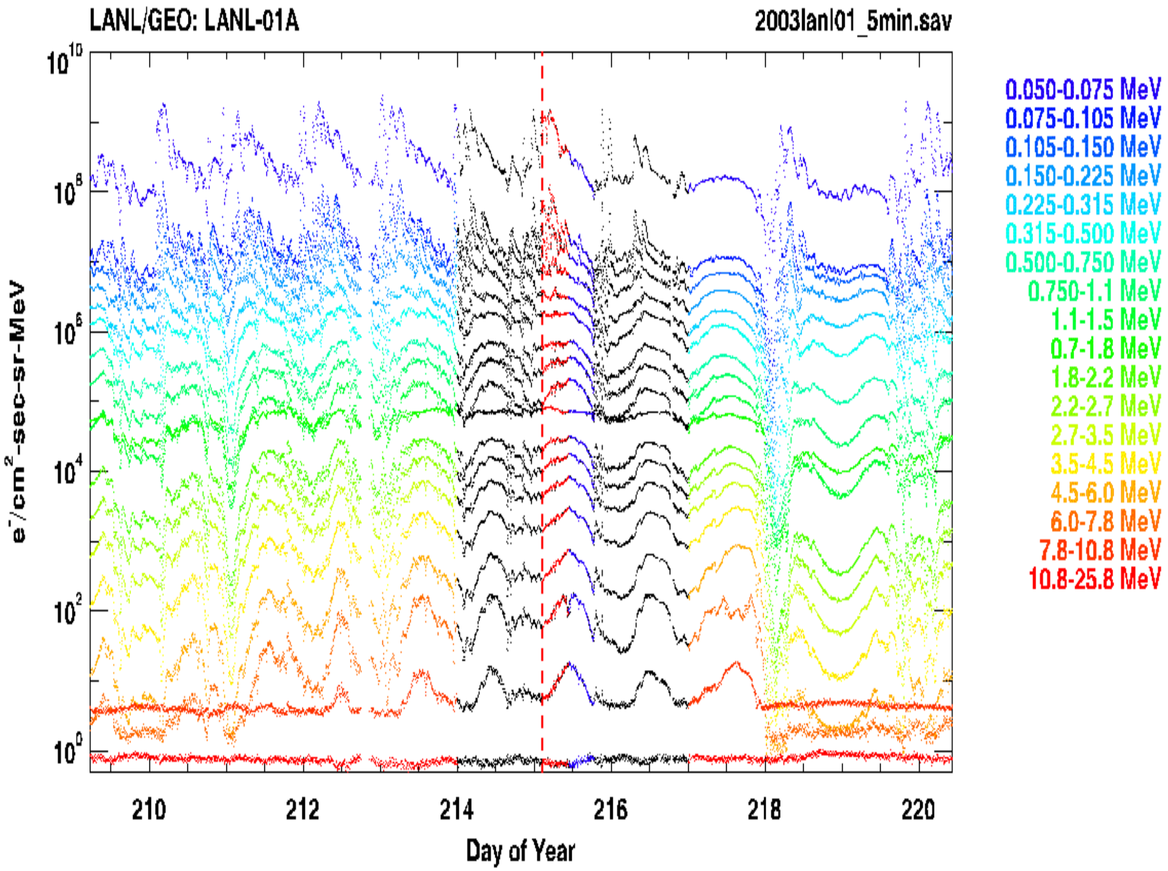
$$\sigma_{radiation} = k\left(\frac{d\gamma}{dt}\right)^{\alpha} \quad 0.5 < \alpha < 1.0$$

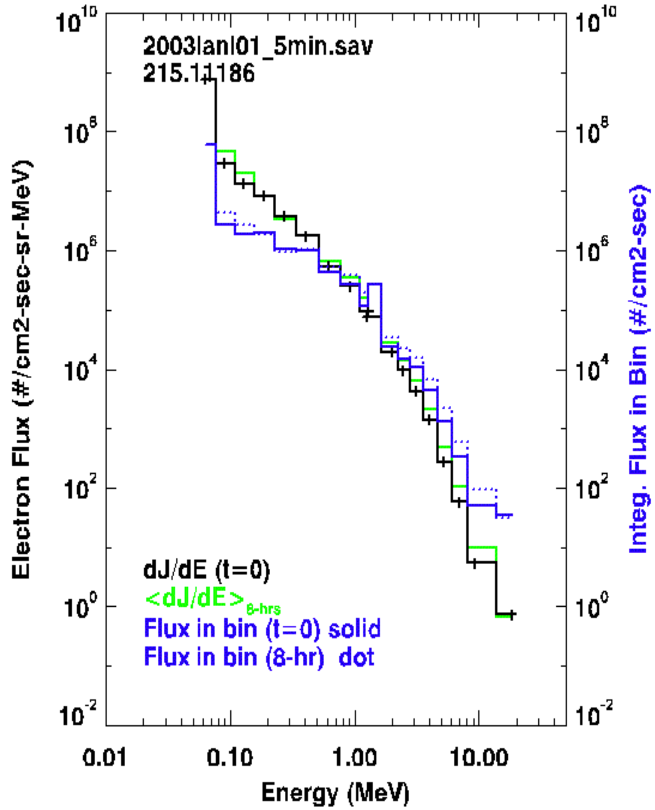
EVA Suit Study Environment



EVA Suit Study Environment

geo_flux_ts_215.11186.txt → test_env.txt





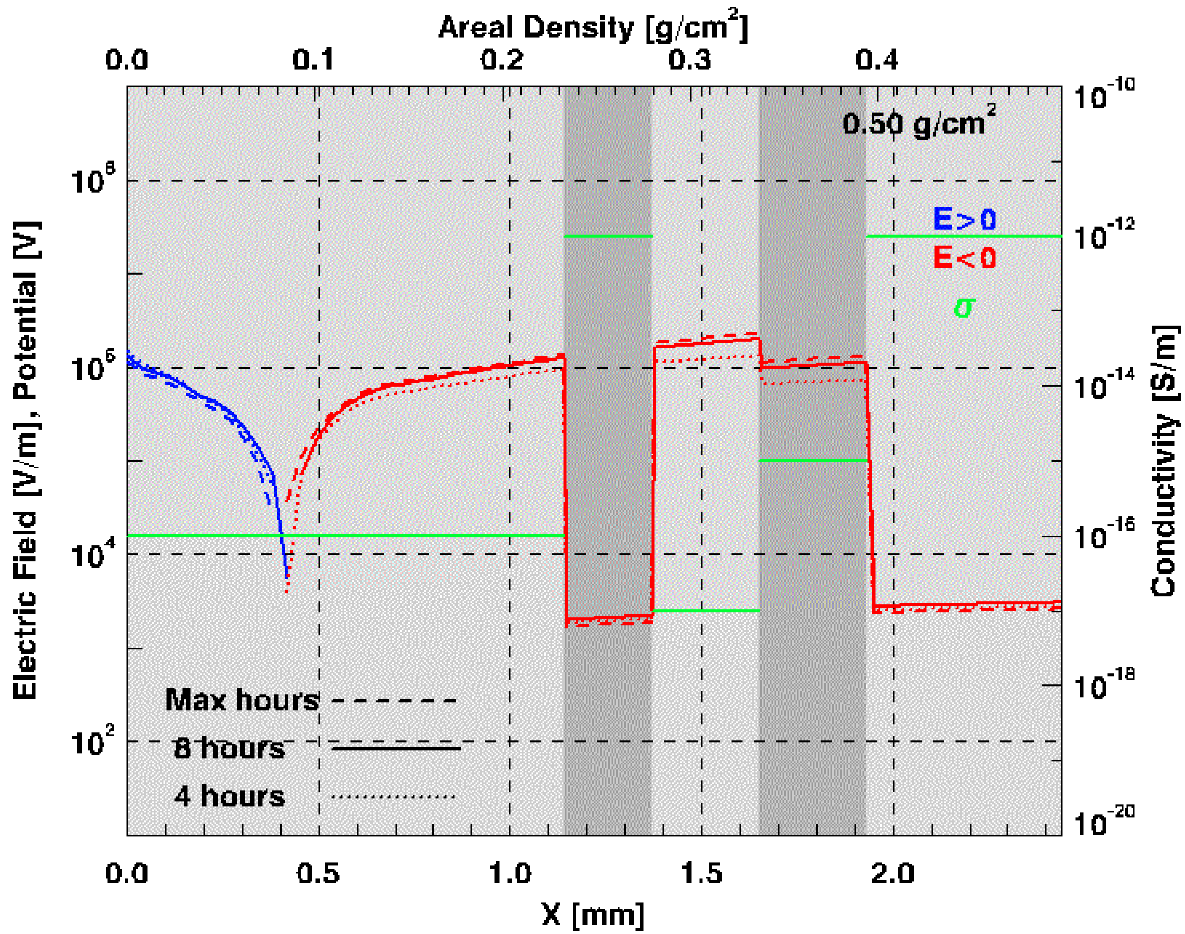
8 hours 16 hours

Interpolation records for filling data gaps

Arms and Lower Torso

Current Design*

Layer	κ	σ (S/m)	Depth (mm)
1	2.0	10^{-16}	1.14
2	2.0	10^{-12}	1.37
3	2.0	10^{-17}	1.65
4	4.0	10^{-15}	1.93
5	2.0	10^{-12}	2.44



$Z_{eff} = 6$

$A_{eff} = 12$

2.04 g/cm^3

Kp = 10^{-14} S-sec/m-rad

$\Delta = 0.7$

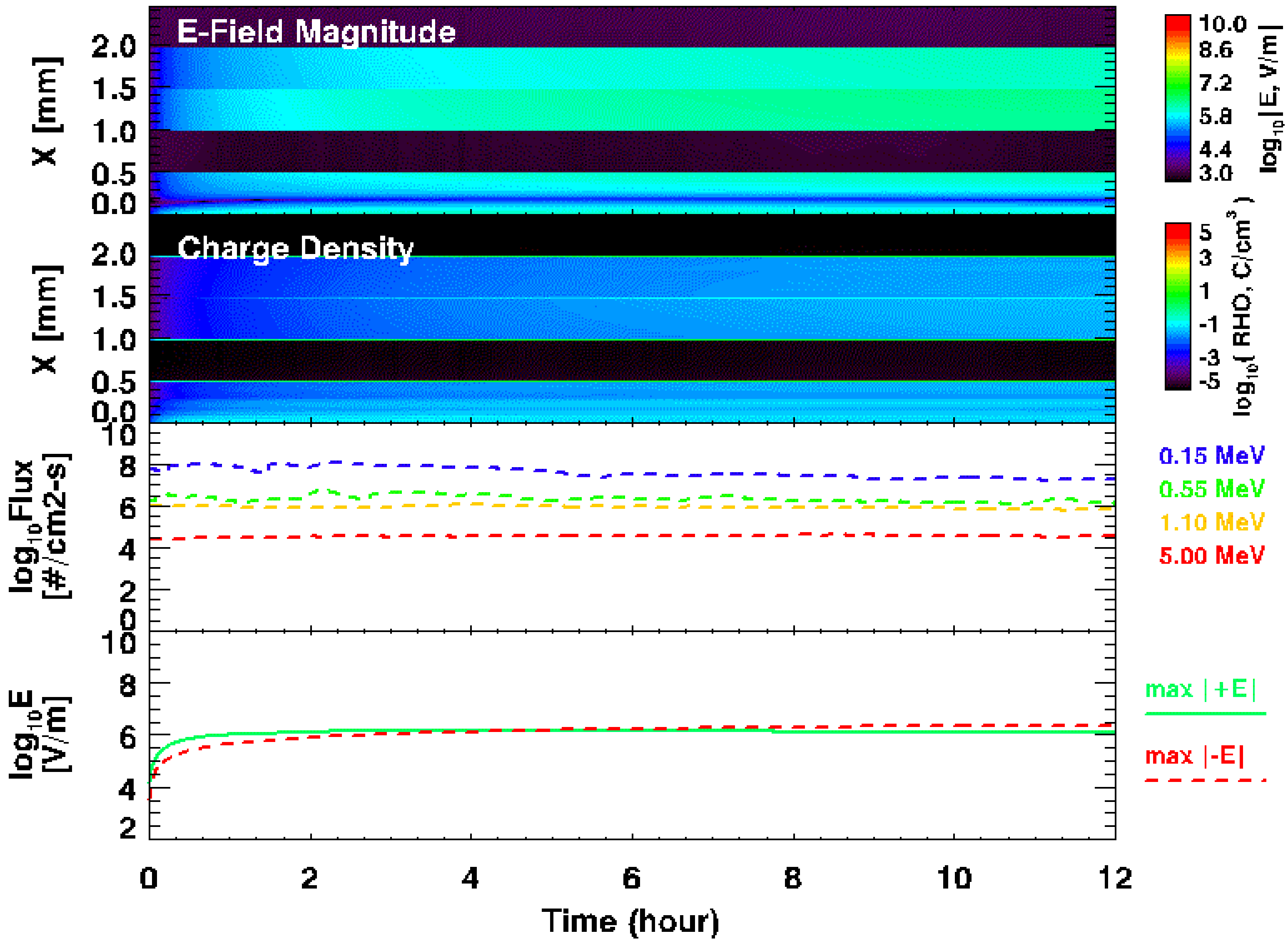
$\Delta T = 1.0$ sec

*Using material spec for nylon conductivity

σ = 10^{-12} S/m

geo_flux_ts_215.11186.txt → test_env.txt

Arms and Lower Torso

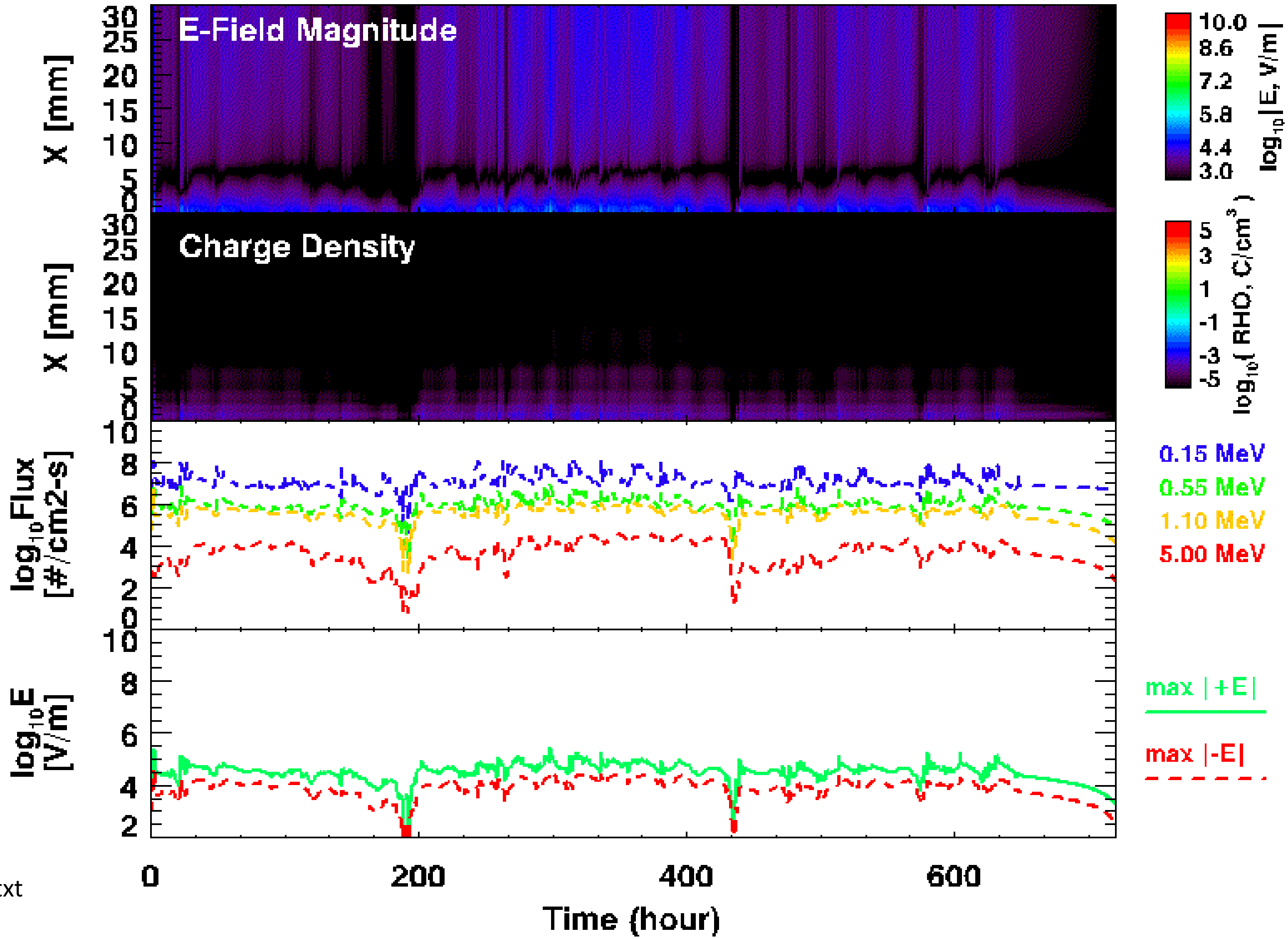


Case 1c

30 mm
0.14 g/cm3
κ=1.13
10^{-13} S/m
τ~100 sec

Simulated:
30 days
(720 hours)

Δt=30 sec



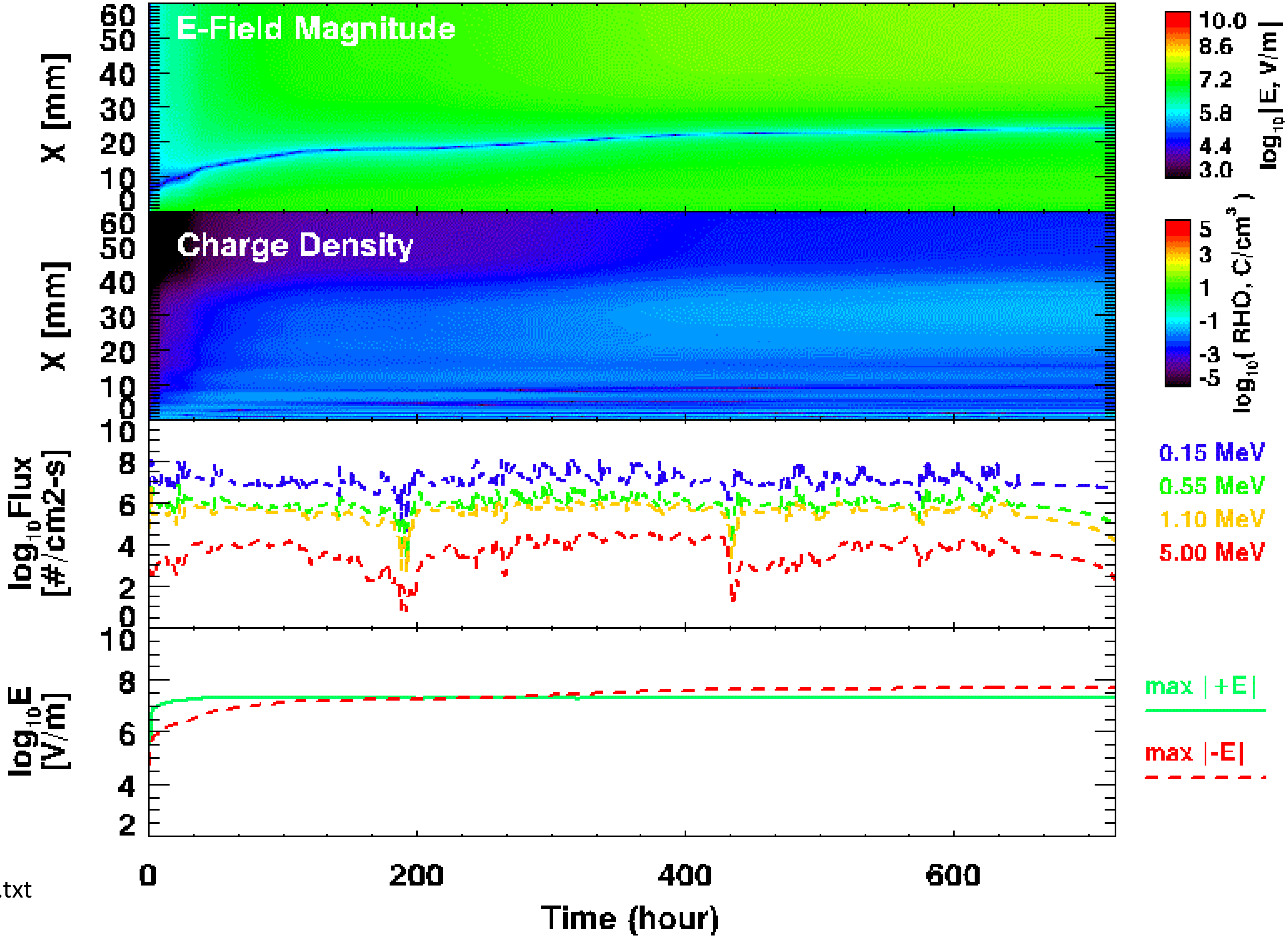
LANL-01 2003
geo_flux_ts_1.0017361.txt
30 days

Case 2a

60 mm
0.14 g/cm3
κ=1.13
10^{-19} S/m
τ~1157 days

Simulated:
30 days
(720 hours)

Δt=300 sec

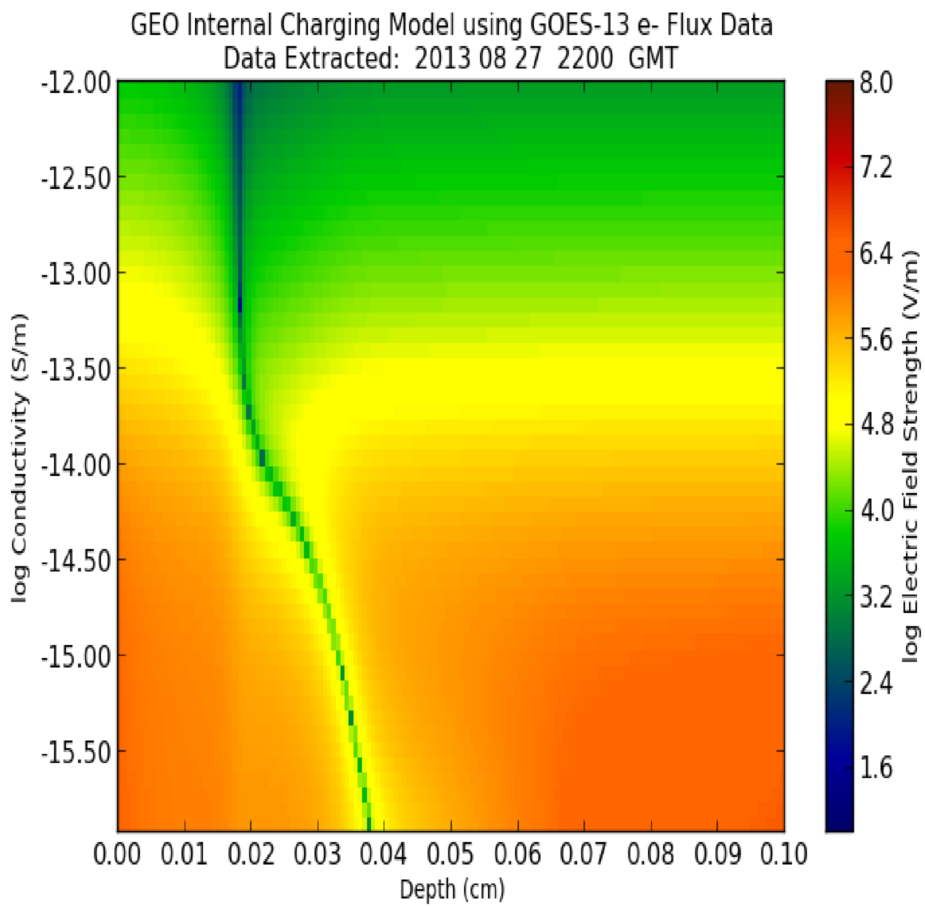


LANL-01 2003
geo_flux_ts_1.0017361.txt
30 days

Geostationary Orbit Internal Charging Tool

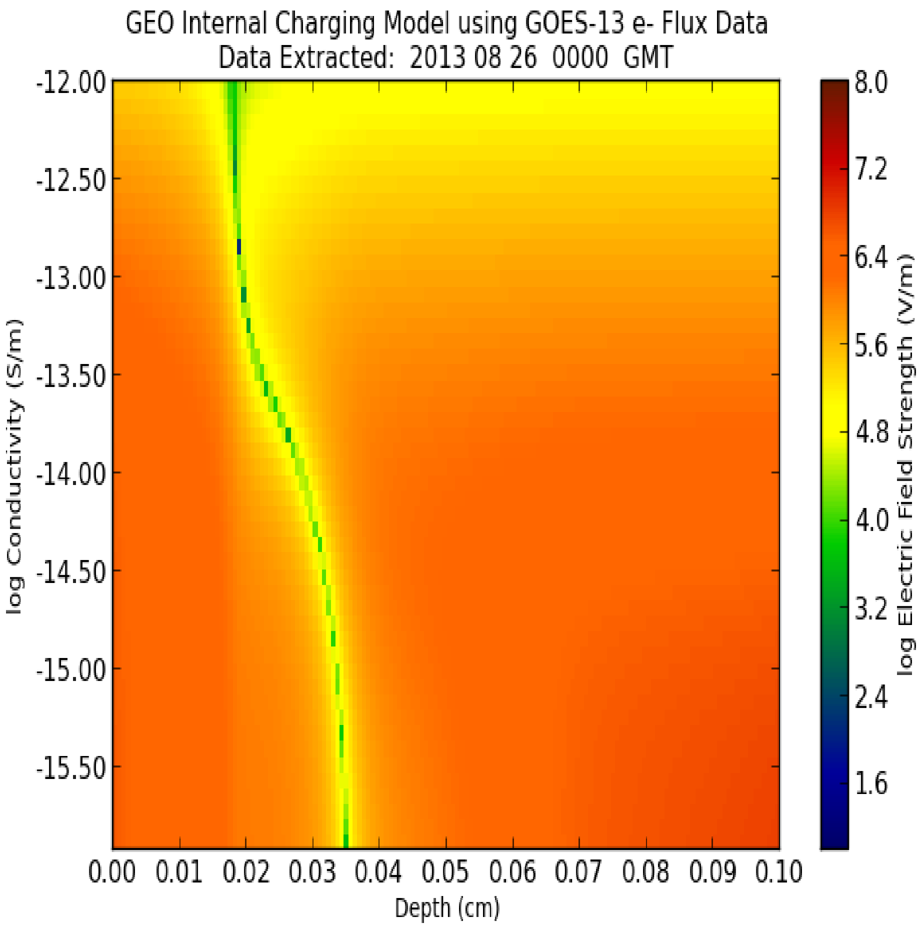
Time constant for charge decay through conduction: $\tau = \kappa\varepsilon_0/\sigma$

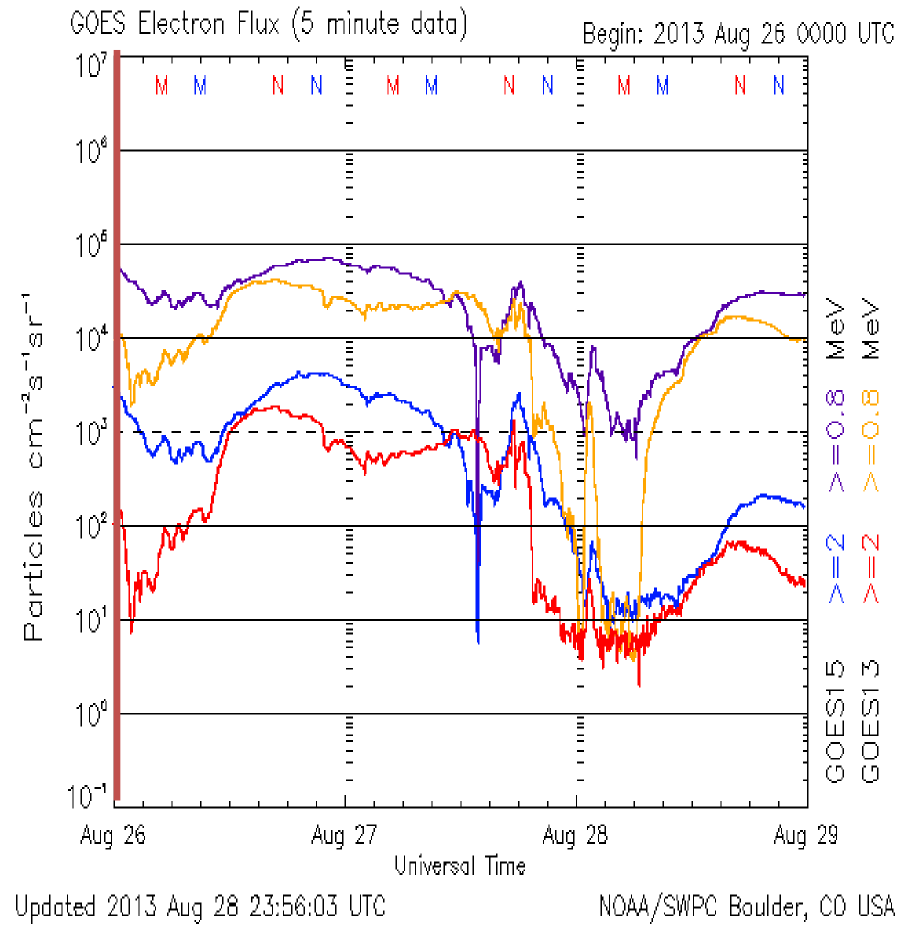
κ	σ (S/m)	τ
2	10^{-12}	~18 sec
2	10^{-13}	~3 min
2	10^{-14}	~30 min
2	10^{-15}	~5 hr
2	10^{-16}	~2 days



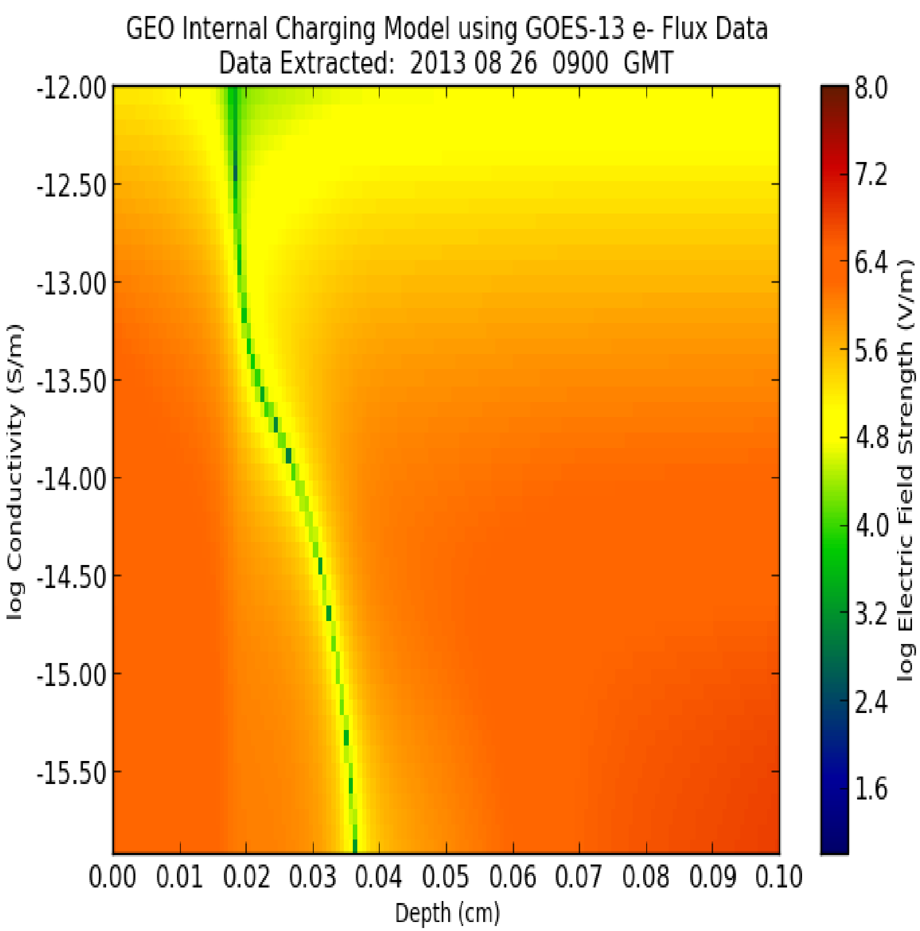
Electric fields resulting from internal (deep dielectric) charging as function of depth in dielectric material and electrical conductivity. Fields are updated at 5 minute intervals using NOAA GOES >0.8 MeV, >2.0 MeV electron data.

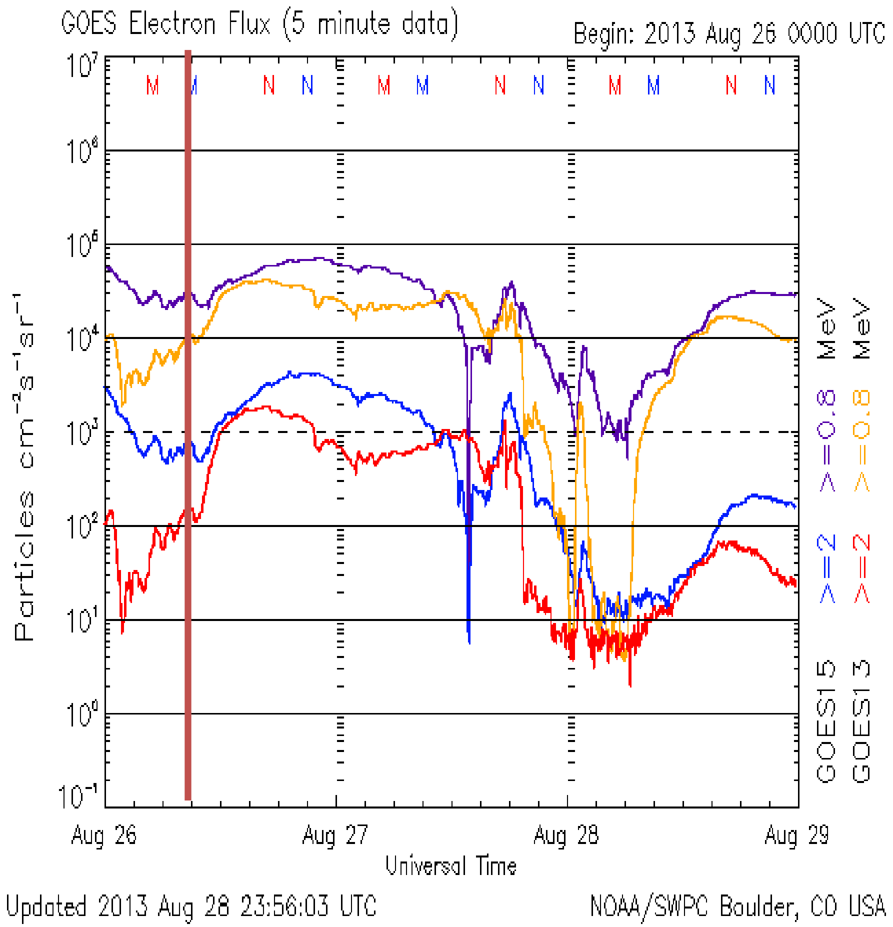
Geostationary Orbit Internal Charging Tool





Geostationary Orbit Internal Charging Tool





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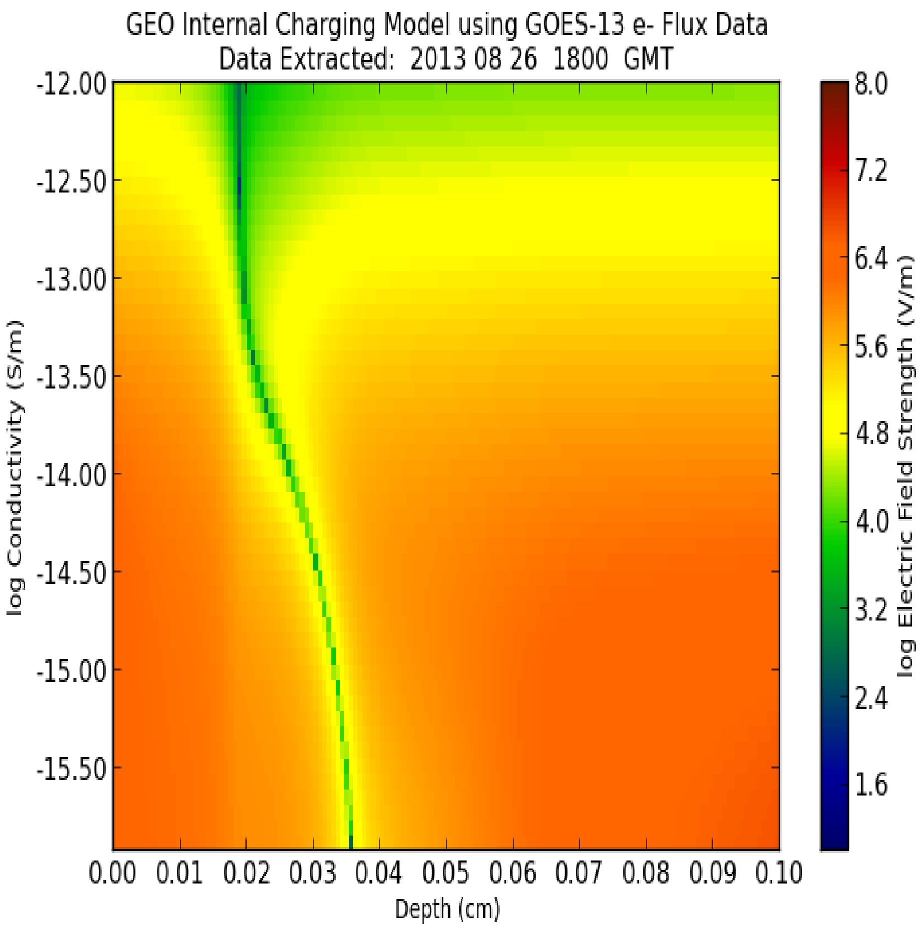

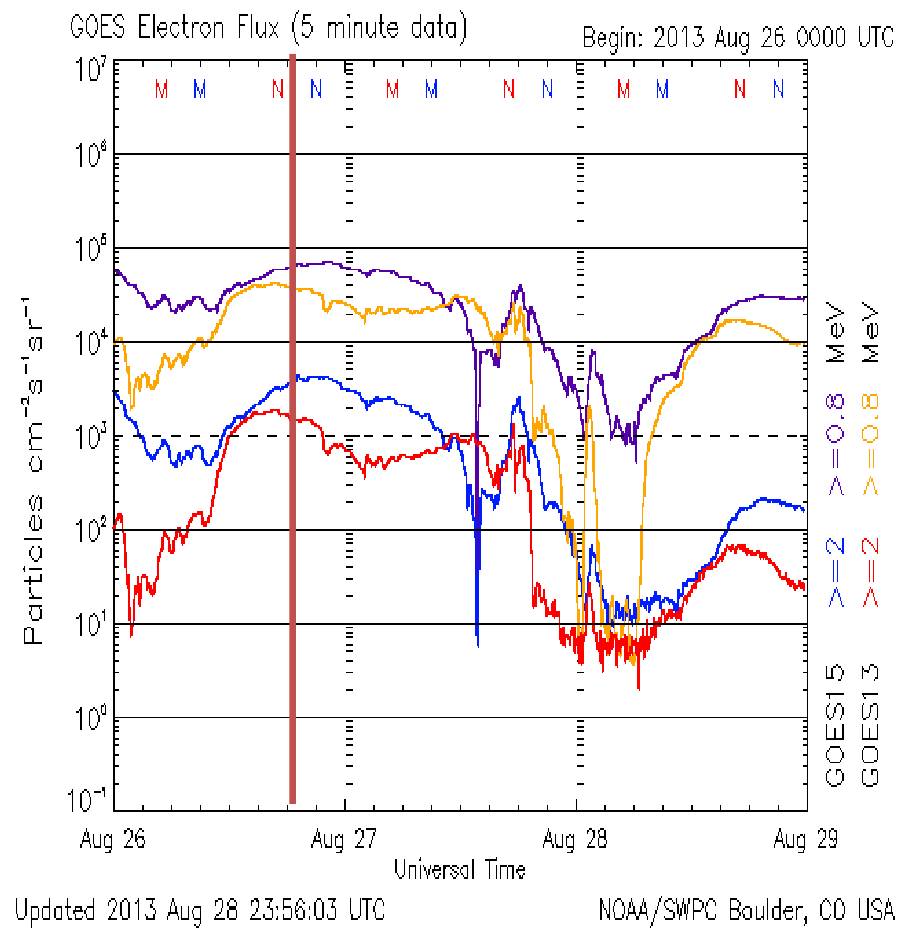

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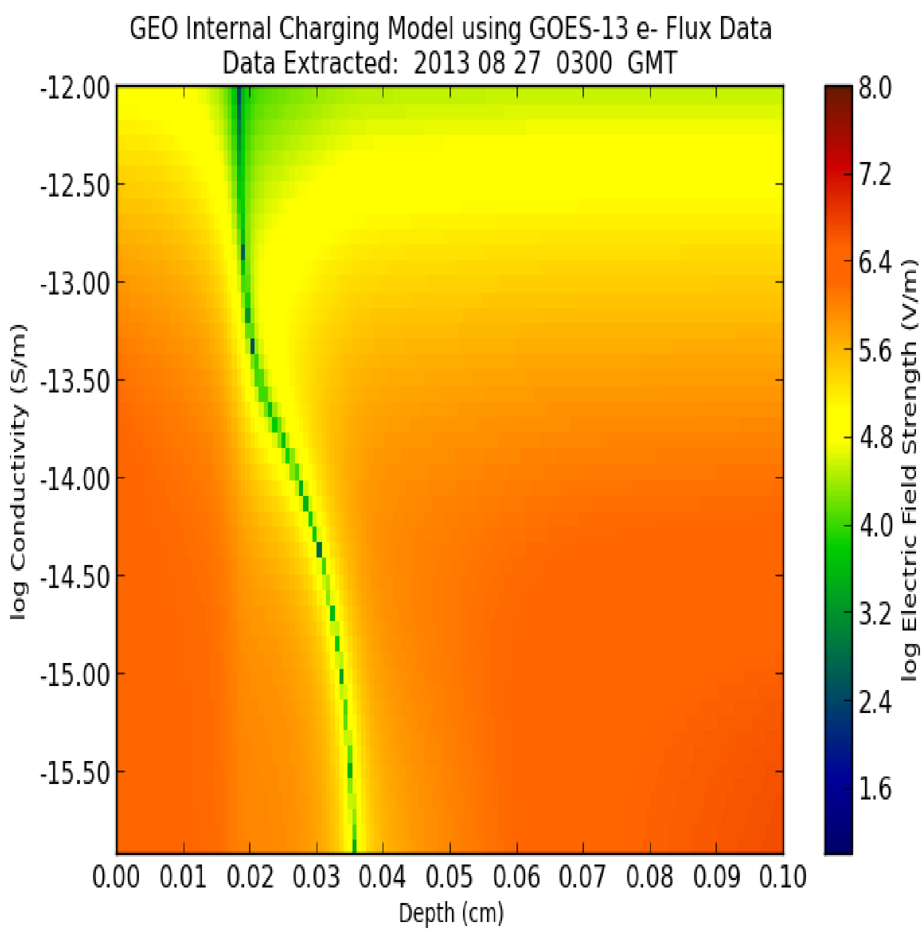

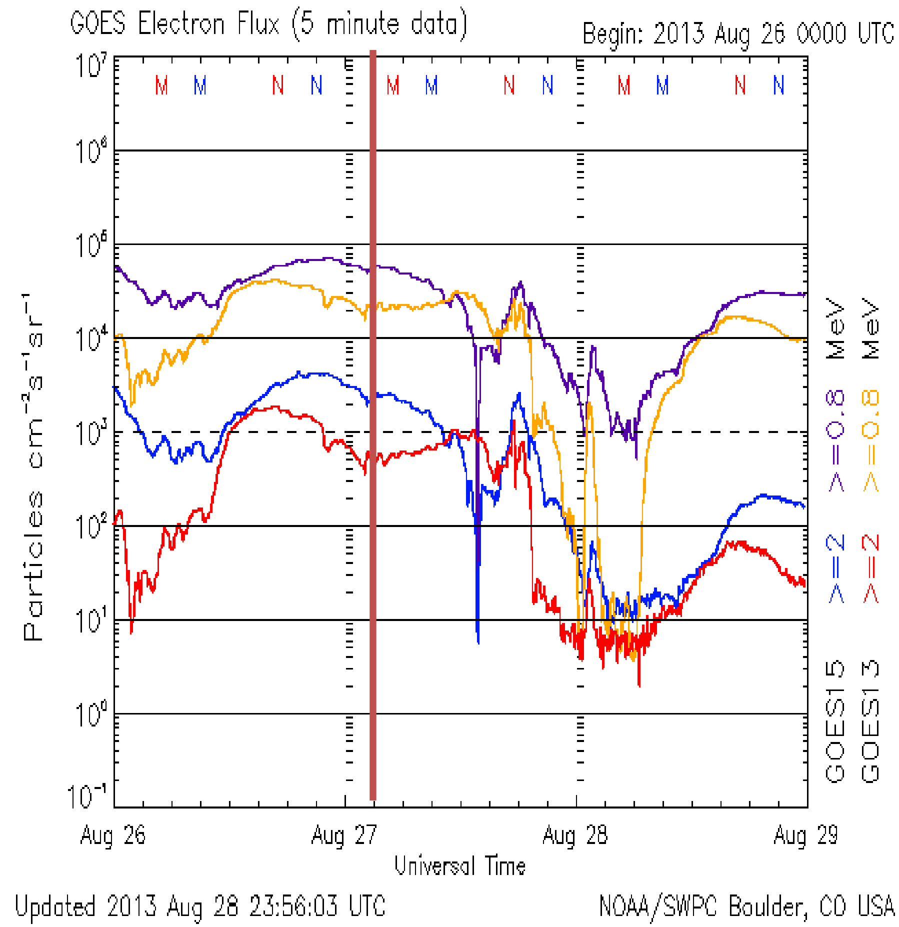

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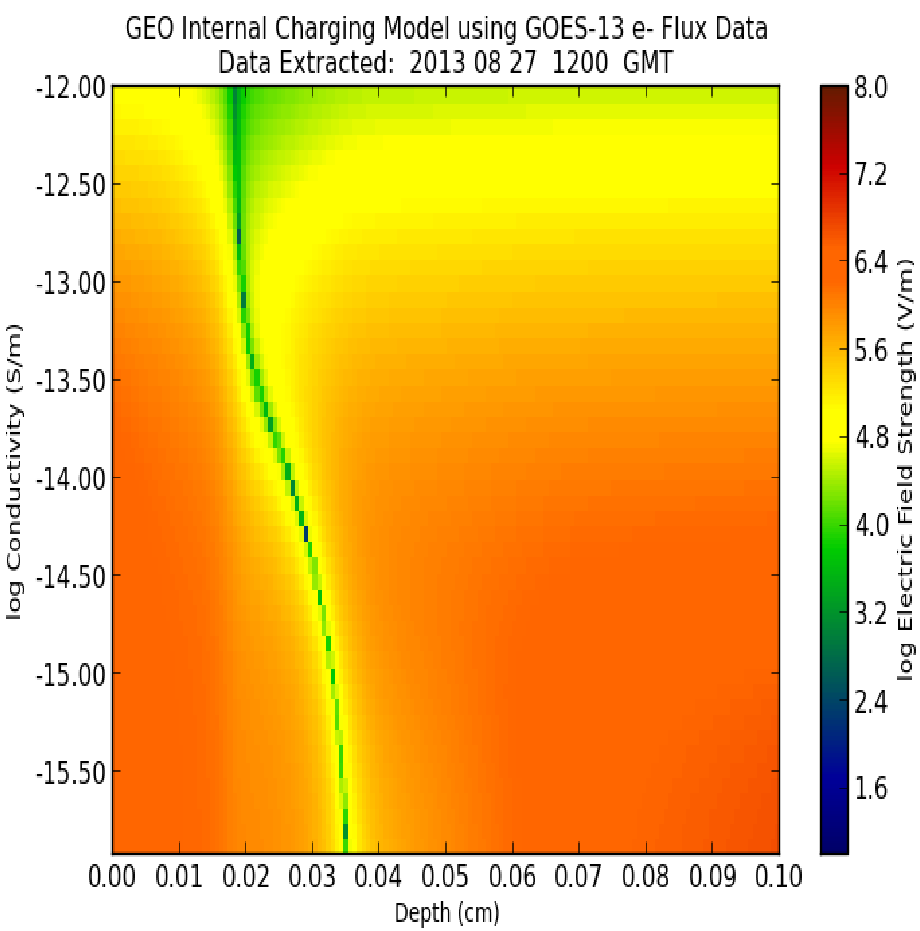

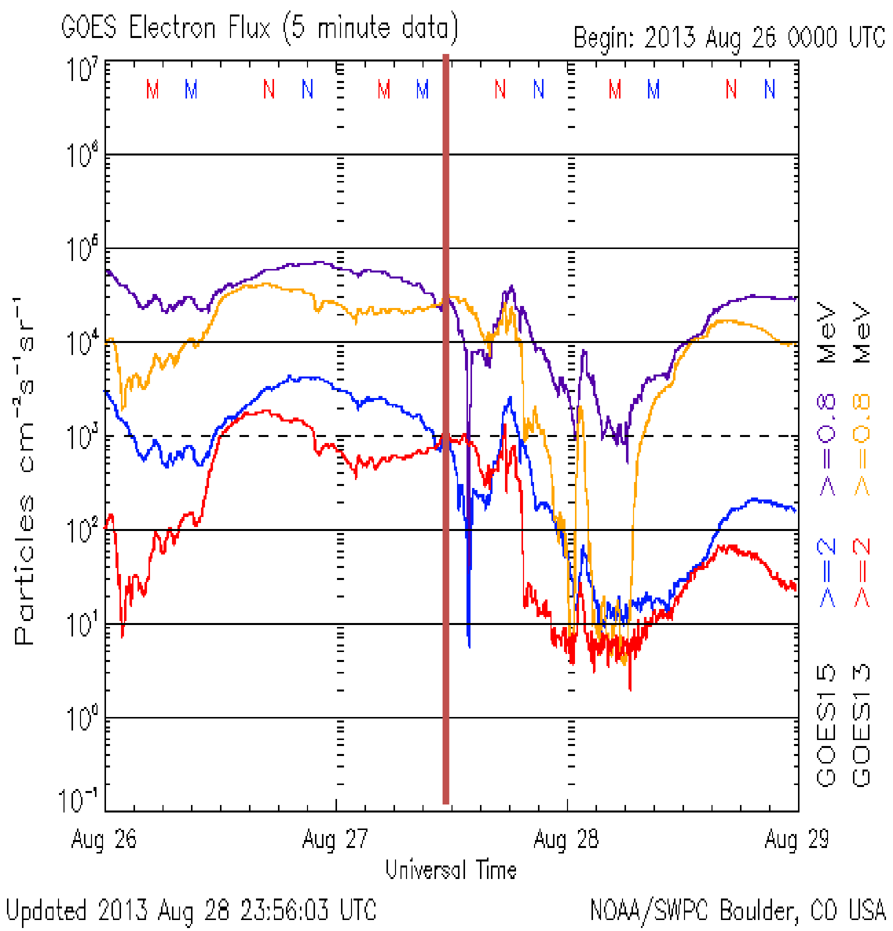

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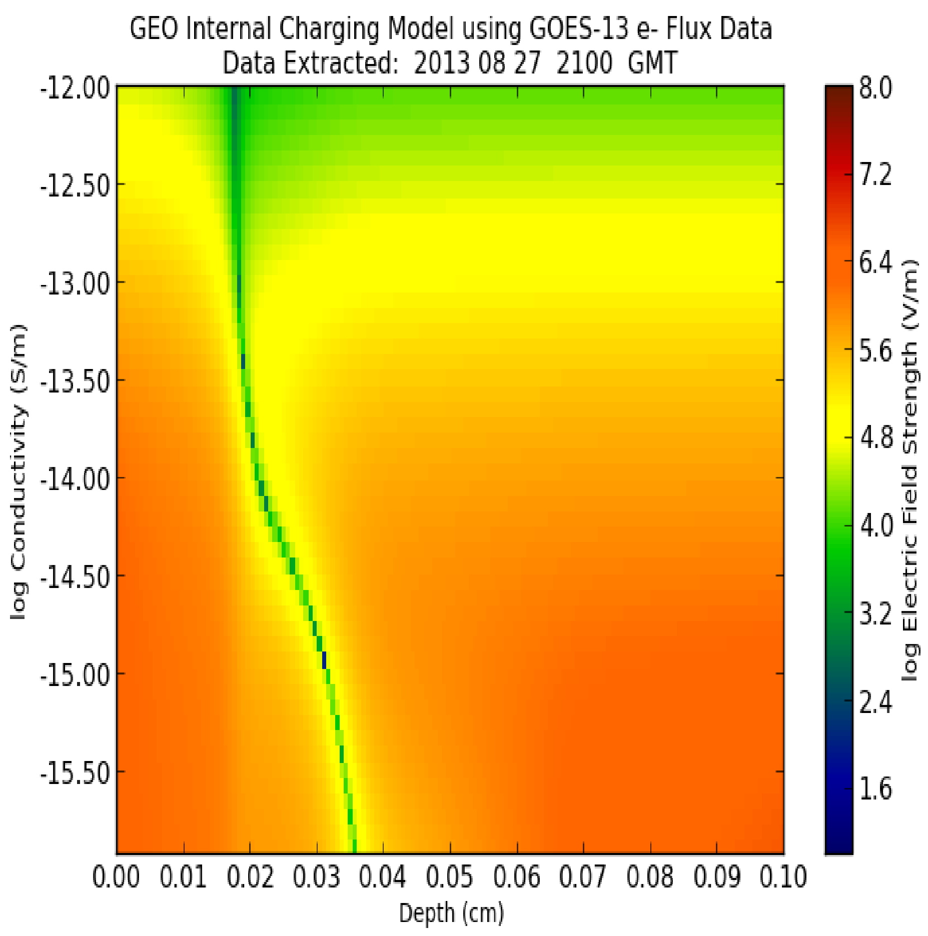

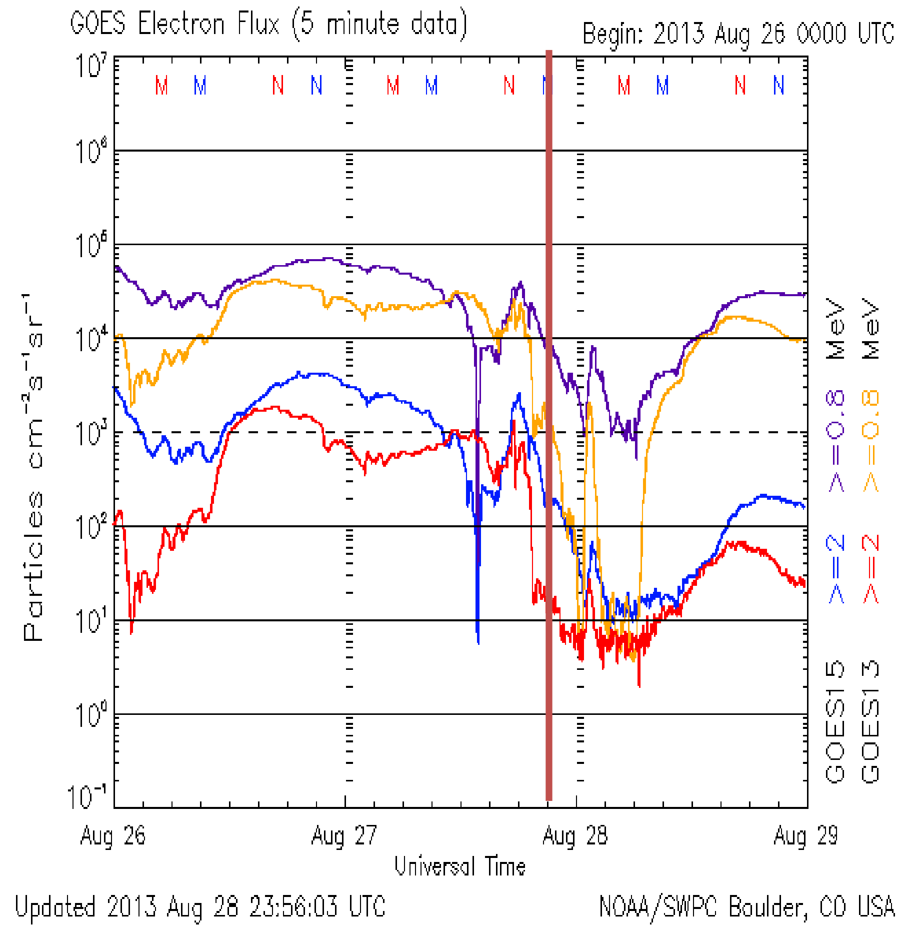

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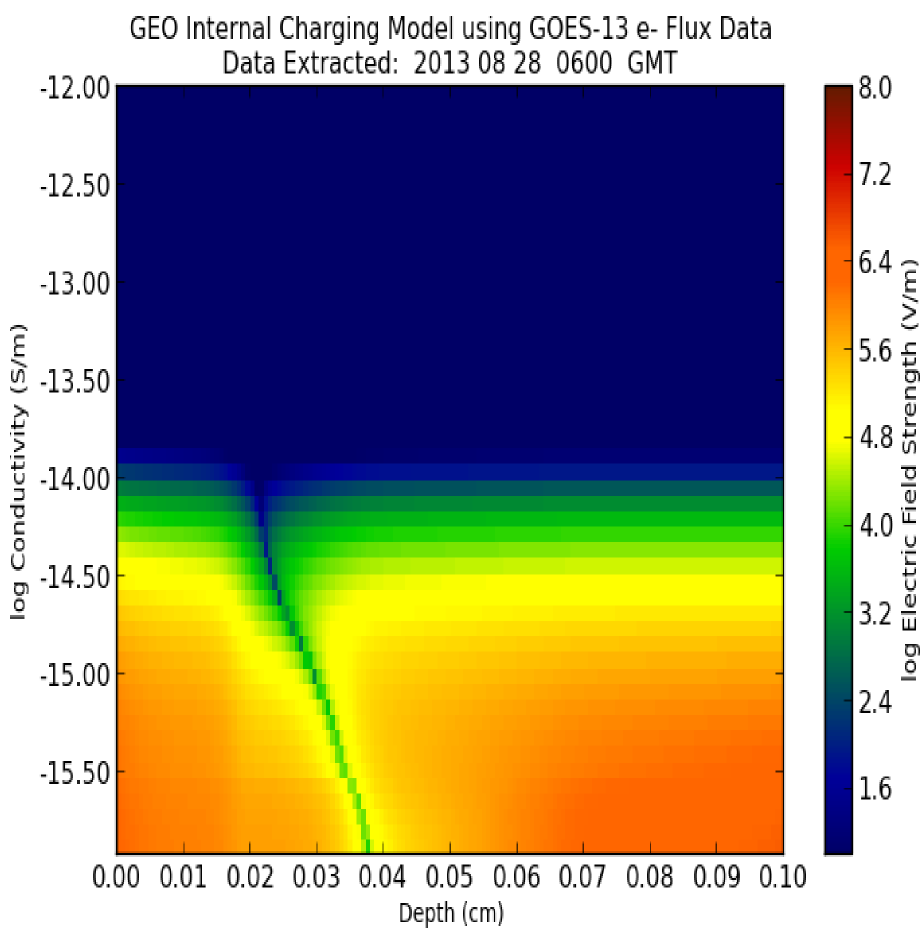

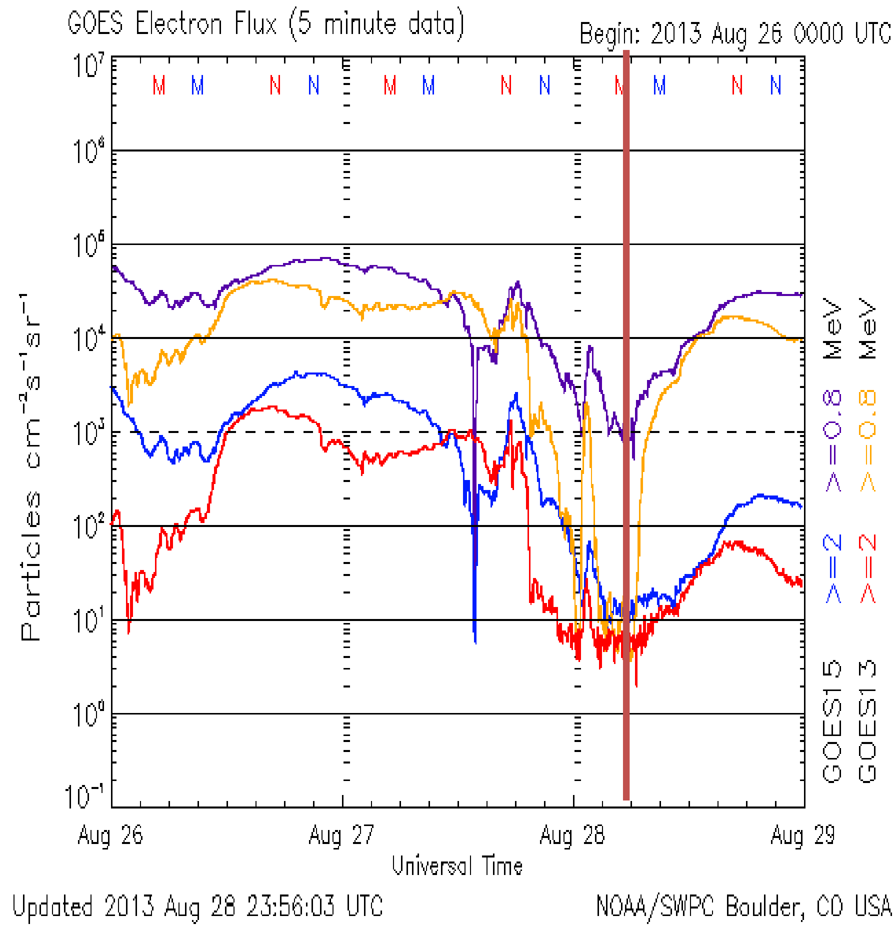

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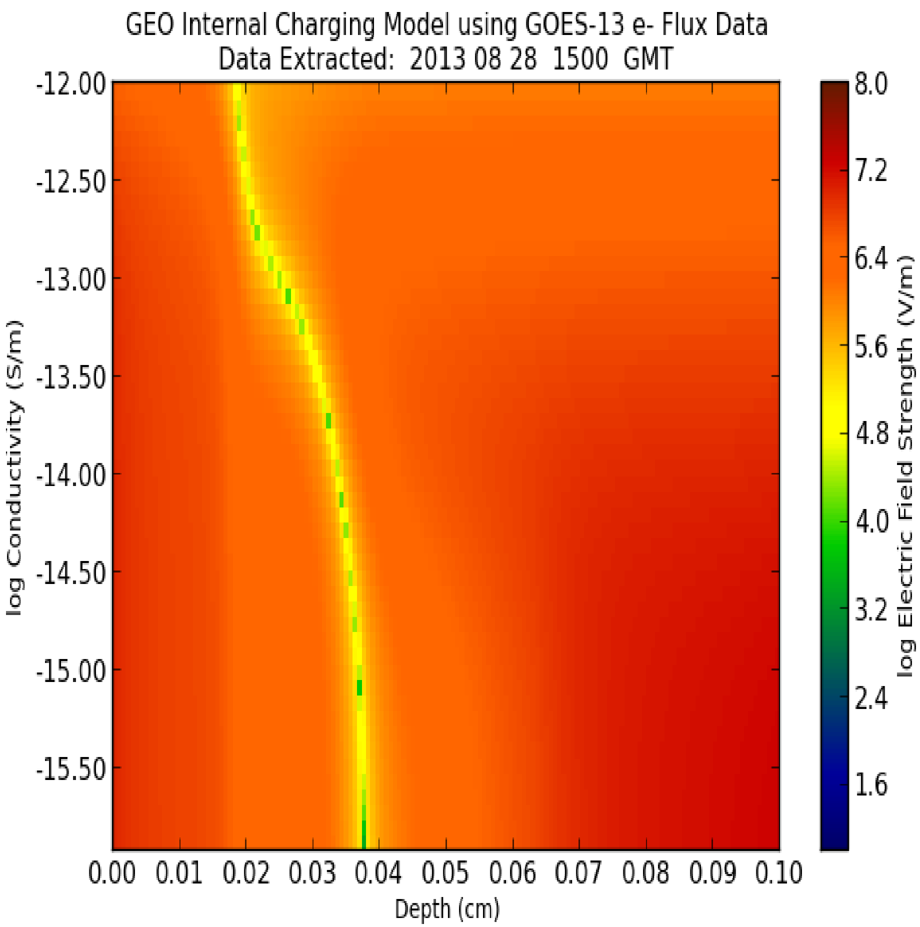

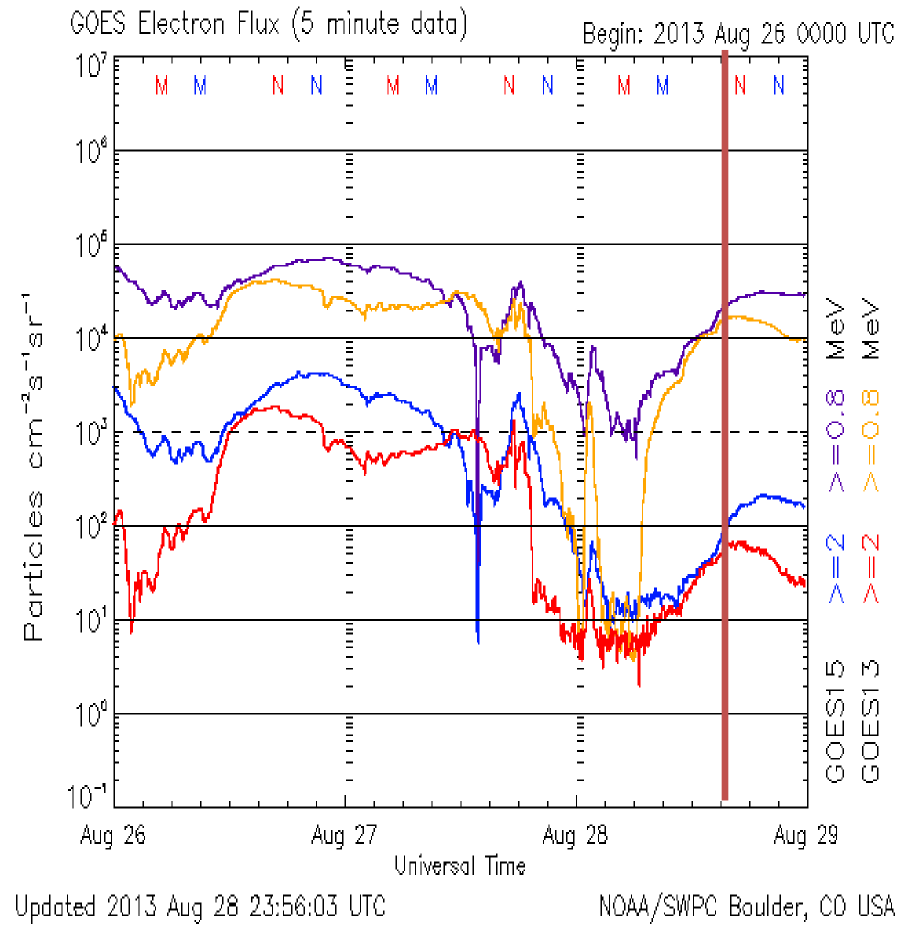

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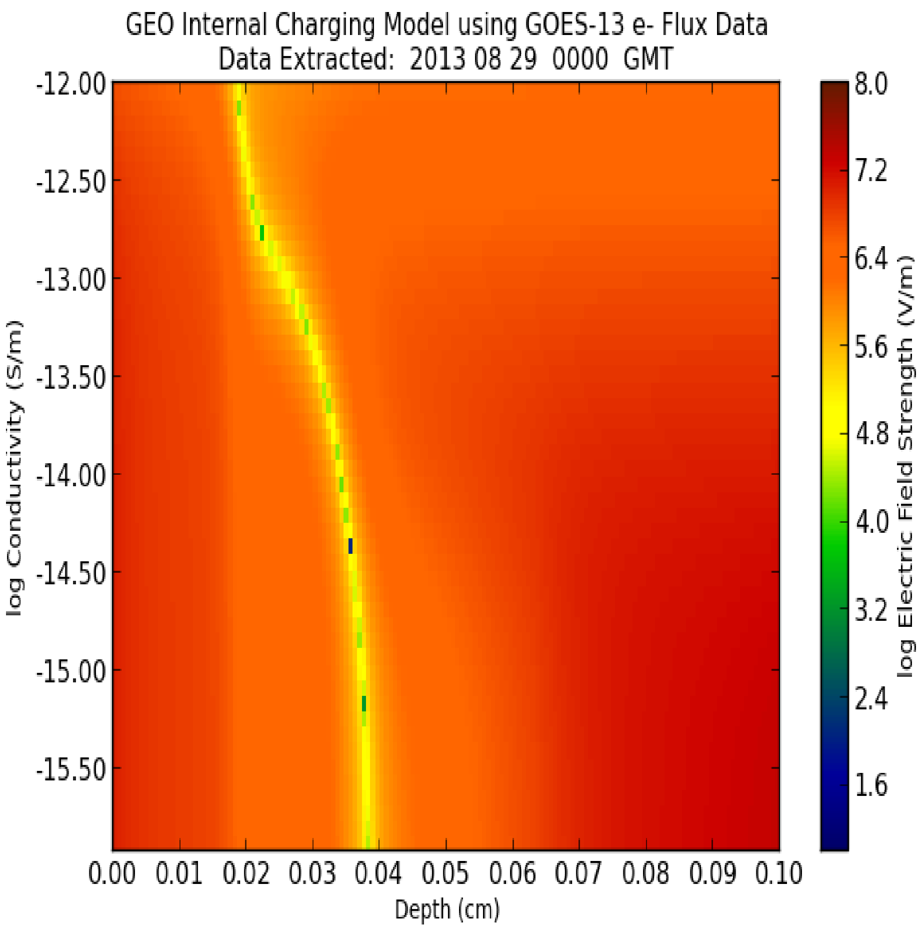
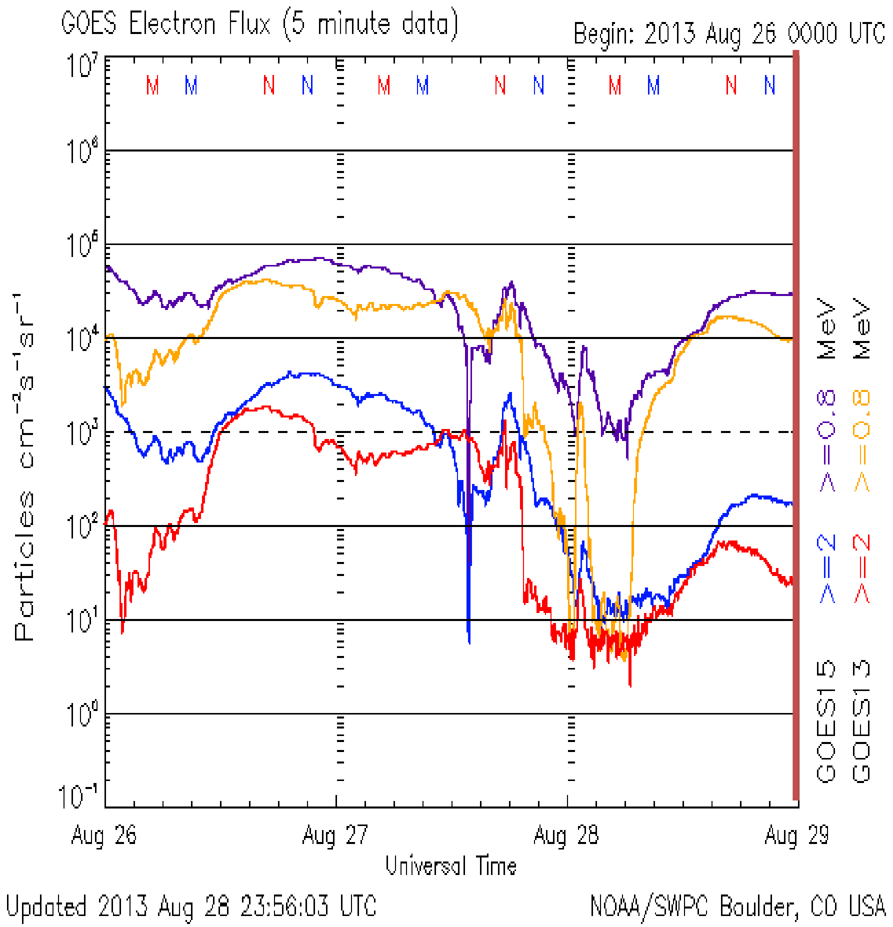
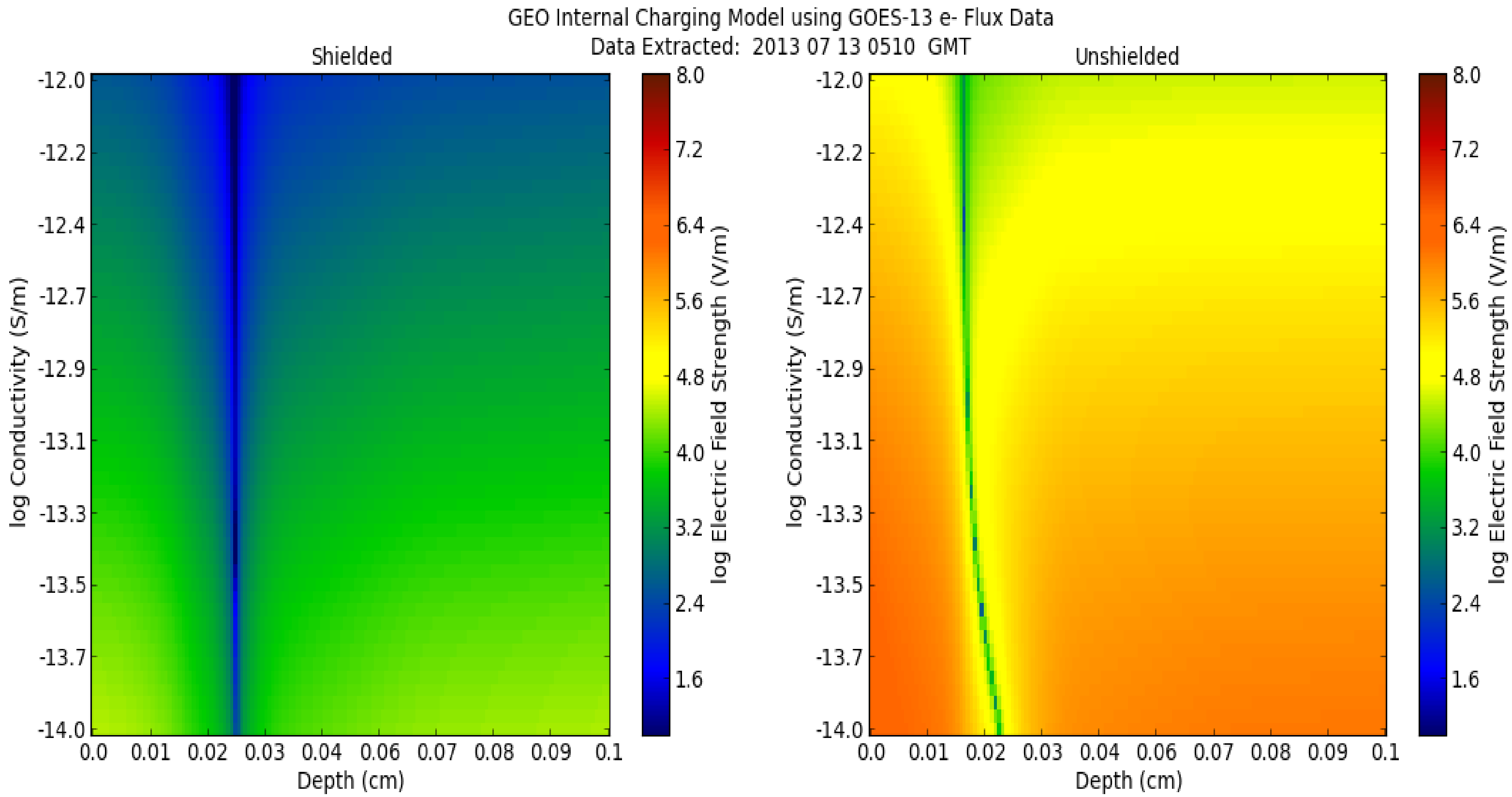




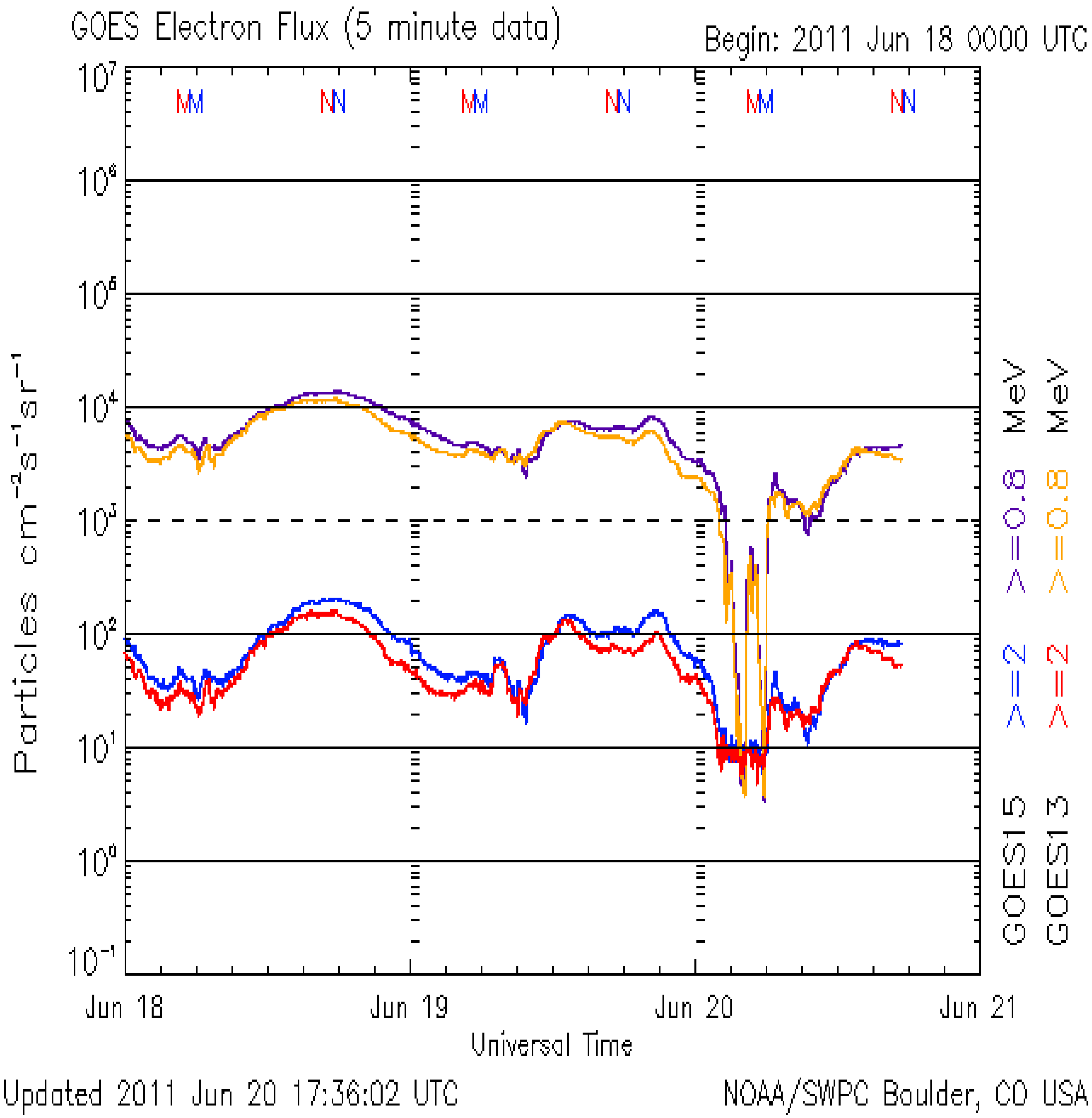
Radiation Shielding Option



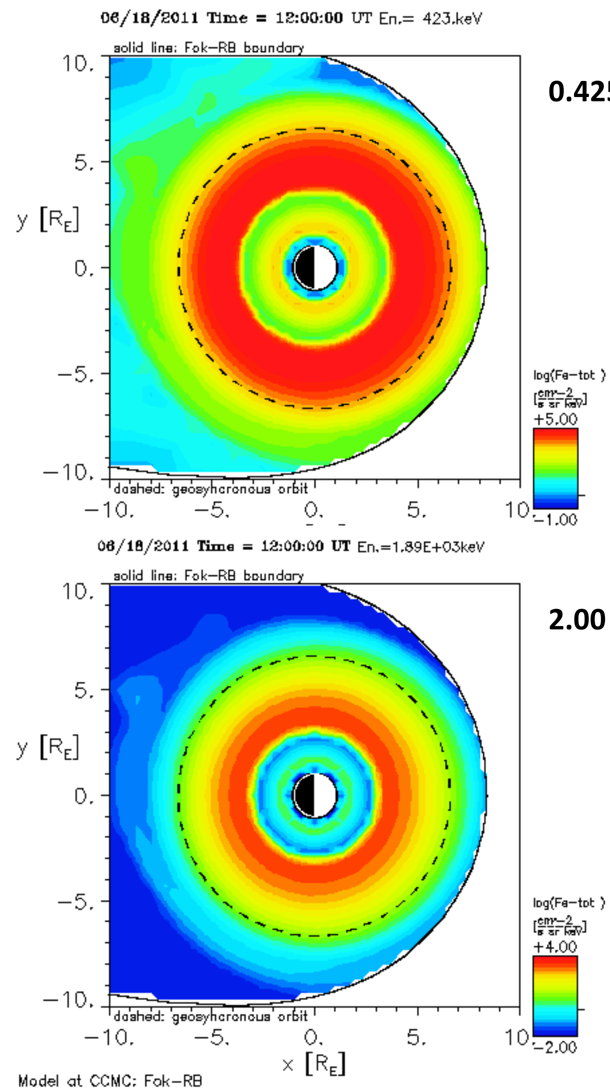
0.069 g/cm2 Al shielding
(0.256 mm)

no shielding

Input Data Options



Fok Radiation Belt Model [iswa.ccmc.gsfc.nasa.gov]



0.425 MeV

2.00 MeV

LEO Internal Charging Model

- 1-D internal charging simulation treating electron flux responsible for charging dielectric materials (or isolated conductors) covered by thin shielding (e.g., MLI):

$$\kappa\varepsilon_o \frac{dE}{dt} + \sigma E = J_p$$

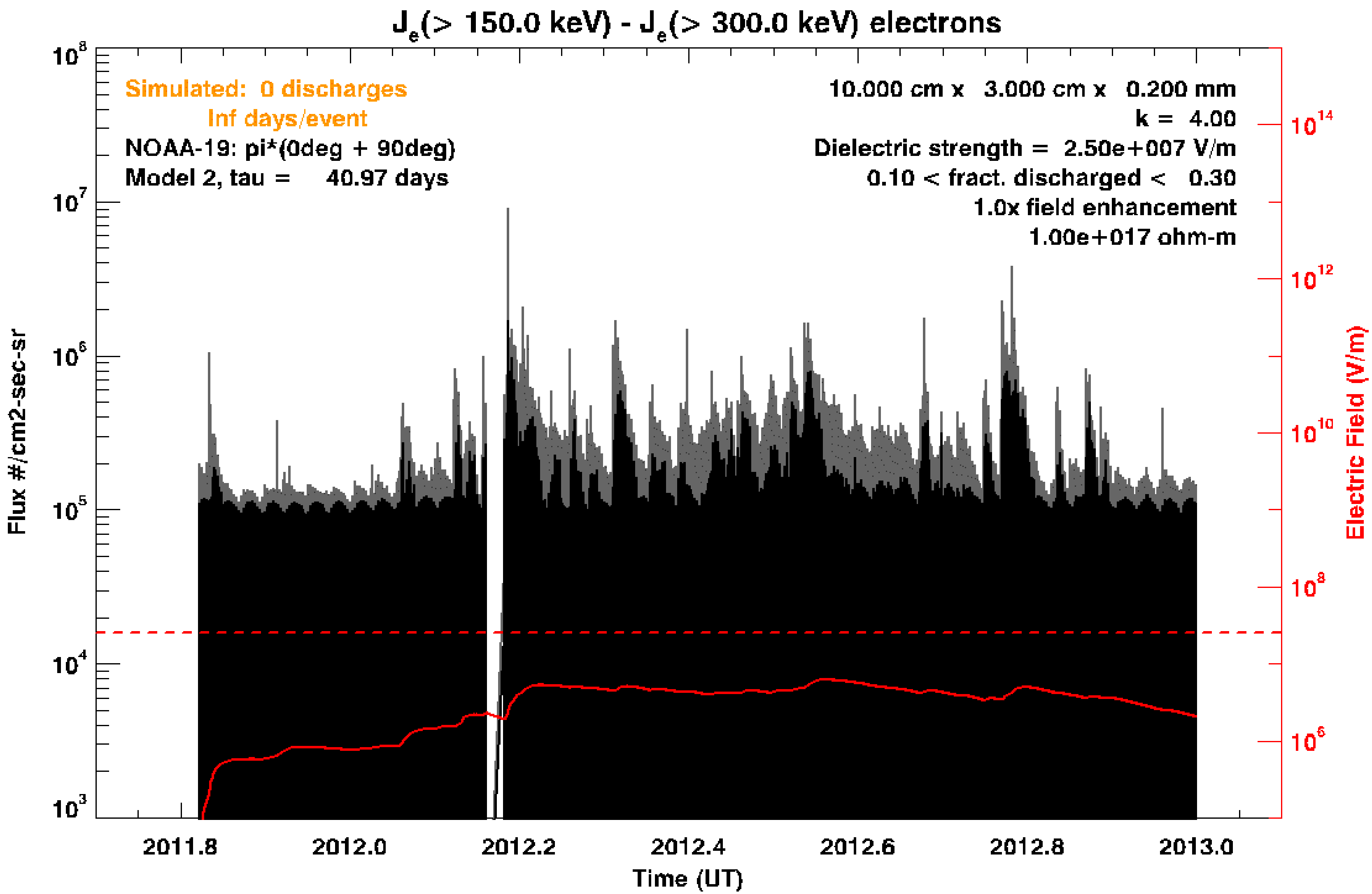
where J_p is the integral electron current density penetrating the MLI shielding, κ is the dielectric constant , ε_0 the permittivity of free space, and σ the electrical conductivity of the dielectric material

- Compute electric field E and potential Φ as function of time using electron flux measurements from NOAA-19 for the incident electron current density, J_p

- Conductivity σ due only to "dark" conductivity, neglect radiation induced conductivity
  - Charge loss process due to conduction to ground slows charge accumulation rate and limits ESD events in lower flux environments
  - Charge, electric field will establishes an equilibrium $E \sim J/\sigma$ if charging time constant $\tau=\kappa\varepsilon_o/\sigma$ for charge loss through conduction is short compared to exposure time
  - Finite amount of time required for charge to decay through conduction after exposure to electrons

- Electric field enhancement factor included to account for sharp edges

LEO Internal Charging Model



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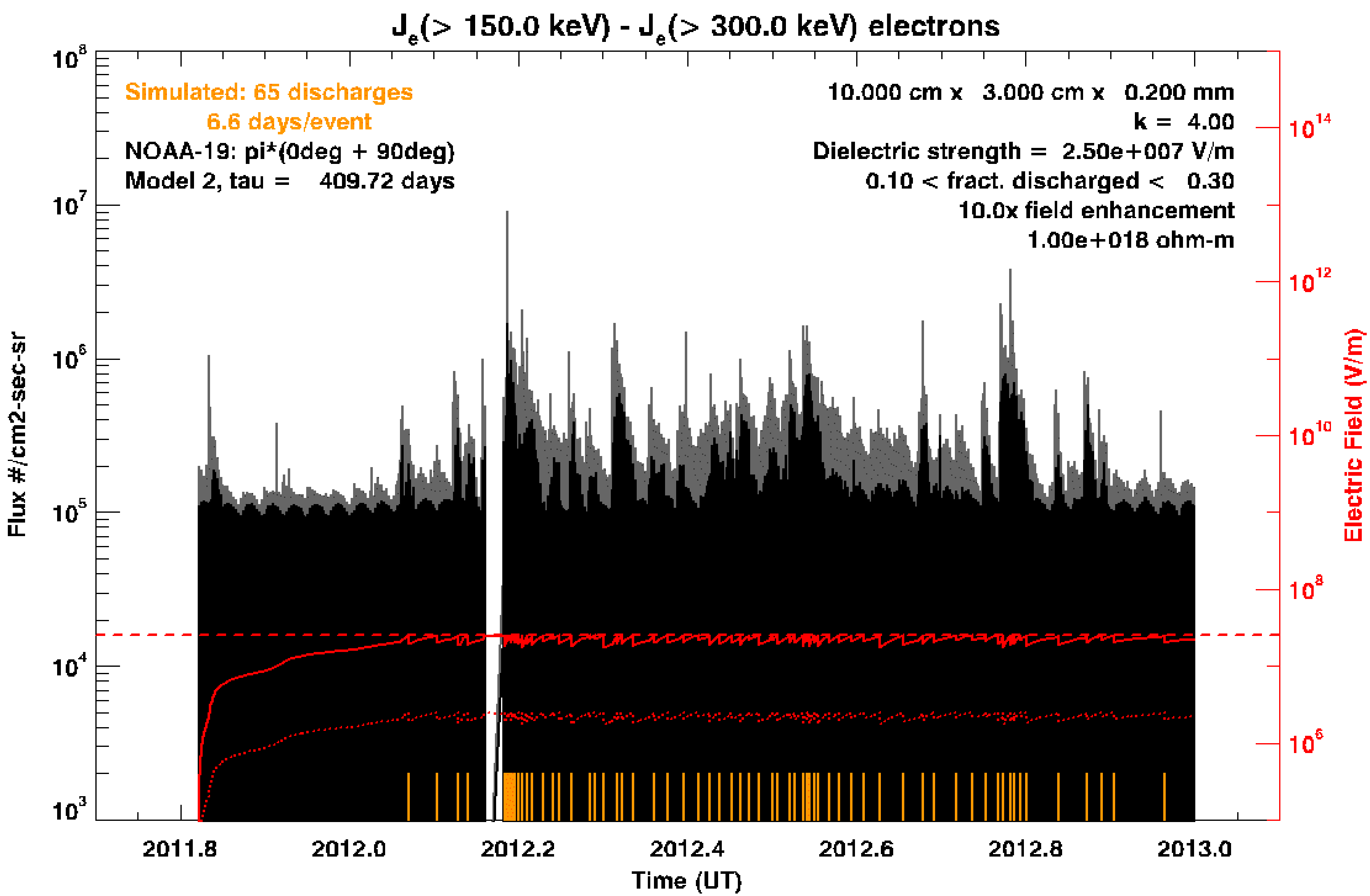

LEO Internal Charging Model

```
      Dimensions (LxWxD):  10.000 cm x   3.000 cm x   0.200 mm
      Volume resistivity: 1.000e+018 ohm-m
                   Kappa: 4.0000
     Dielectric strength: 2.500e+007 V/m
      Efield enhancement:  10.0x
             Capacitance: 5.310e-010 Farads
Conduction time constant:   409.7222 days

 Fraction (f) discharged:  0.100 < f < 0.300

       NOAA-19 electrons:   pi*(0deg + 90deg)
         Electron energy:  150.0000 keV -  300.0000 keV
```

Arc	Decimal Year(UT)	Day of Year(UT)	Fraction Discharged	Surface Voltage (Volts) Before	and After Arc	Arc Energy (mJoule)	Arc Current (Amp) 0.10 us	1.00 us	10.00 us
0	2012.0710	26.9785	0.2283	500.0	385.9	0.0268	6.06e-001	6.06e-002	6.06e-003
1	2012.1039	39.0314	0.2004	500.0	399.8	0.0239	5.32e-001	5.32e-002	5.32e-003
2	2012.1290	48.2109	0.2537	500.0	373.2	0.0294	6.73e-001	6.73e-002	6.73e-003
3	2012.1399	52.2185	0.2410	500.0	379.5	0.0281	6.40e-001	6.40e-002	6.40e-003
4	2012.1837	68.2398	0.2647	500.1	367.7	0.0305	7.03e-001	7.03e-002	7.03e-003
5	2012.1874	69.5824	0.1438	500.6	428.6	0.0178	3.82e-001	3.82e-002	3.82e-003
6	2012.1891	70.2203	0.1002	500.0	449.9	0.0126	2.66e-001	2.66e-002	2.66e-003
7	2012.1909	70.8707	0.1937	500.1	403.3	0.0232	5.14e-001	5.14e-002	5.14e-003
8	2012.1942	72.0668	0.1379	500.0	431.1	0.0170	3.66e-001	3.66e-002	3.66e-003
9	2012.1965	72.9144	0.1782	500.0	410.9	0.0215	4.73e-001	4.73e-002	4.73e-003
10	2012.2000	74.1920	0.2192	500.0	390.4	0.0259	5.82e-001	5.82e-002	5.82e-003

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ISS image: 11 March 2012