Spacecraft Charging Analysis of Large GEO Satellites Using MUSCAT

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September 20, 2010

11th Spacecraft Charging Technology Conference, Albuquerque, NM, USA

Introduction

- Laboratory ESD test on SS/L solar panel based on ISO-11221
  - Secondary arc
  - Power degradation due to primary arcs
- Number of ESDs expected in orbit needed
  - How many ESDs in the test
  - Derivation of overall power degradation at EOL

How to derive

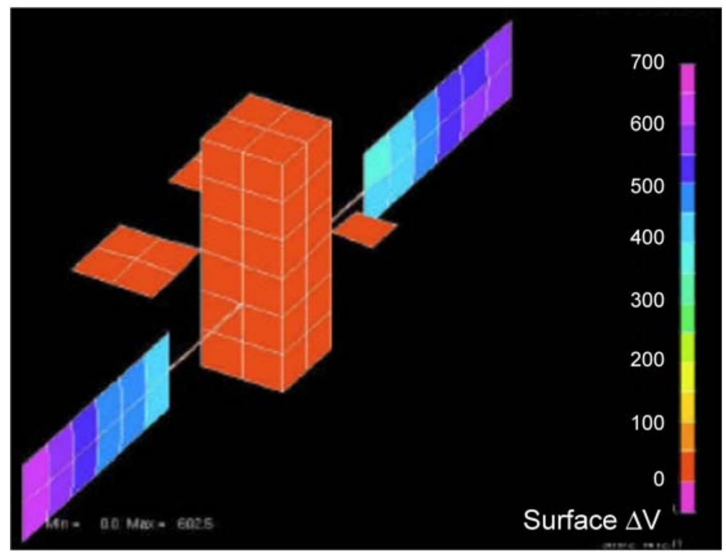
1. List-up all the possible combinations of GEO plasma environment parameters
   – LANL data
2. Spacecraft charging analysis for each case
   – MUSCAT
3. Identify the environment cases exceeding the ESD threshold, ΔV_{th}.
4. For each case identified above, calculate the charging time, t_{chrg}, necessary to reach ΔV_{th}.
5. Derive the probability of occurrence of each case identified in step 3 and the expected total duration in orbit, t_{env}
6. Get the number of ESDs for each case from t_{env}/t_{chrg}.
7. Sum the number of ESD events to derive the total number.

Previous works

- Similar work was done for WINDS (Kizuna) in 2003
- Combination of LANL data and NASCAP/GEO

45,000 arcs in 15 years with ΔV_{th}=400V

Launched to GEO in 2008

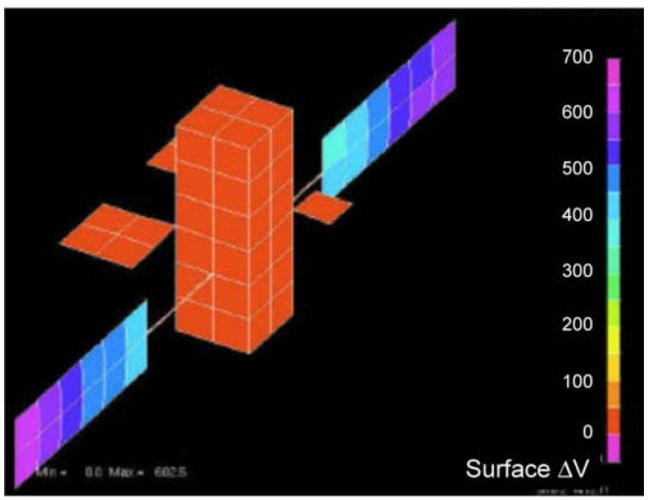


NASCAP/GEO model

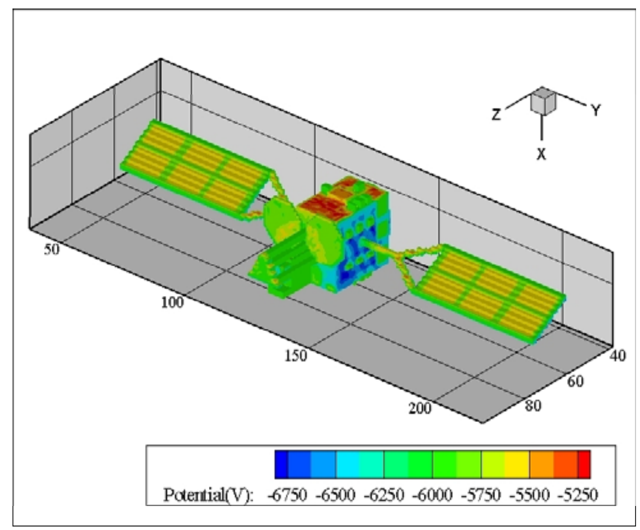
Cho, M., et al, Journal of Spacecraft and Rockets, vol.42, 2005.

Charging Analysis

- For the present work, we used MUSCAT (Multi-Utility Spacecraft Charging Analysis Tool)

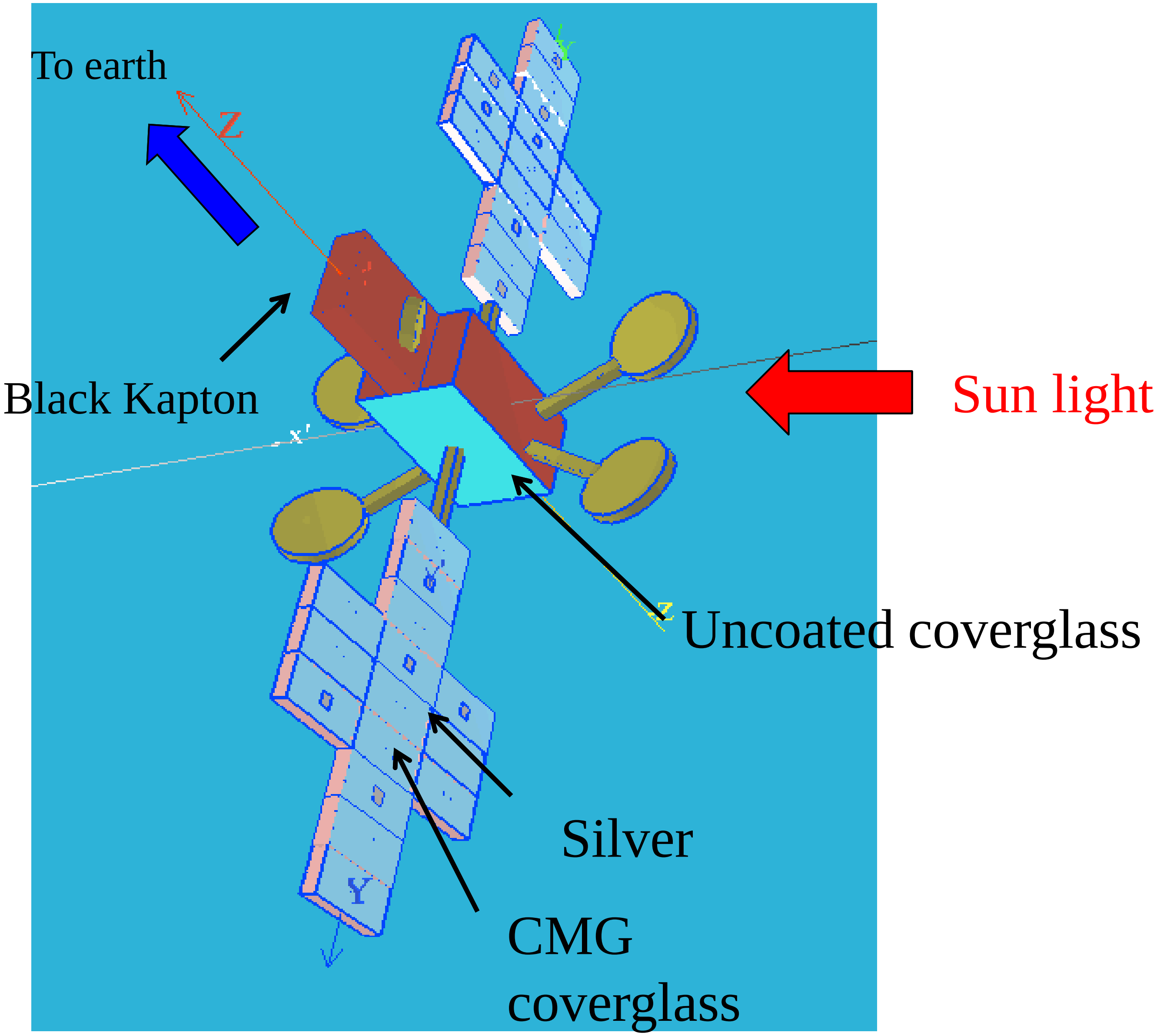


NASCAP/GEO model



MUSCAT model

Satellites studied

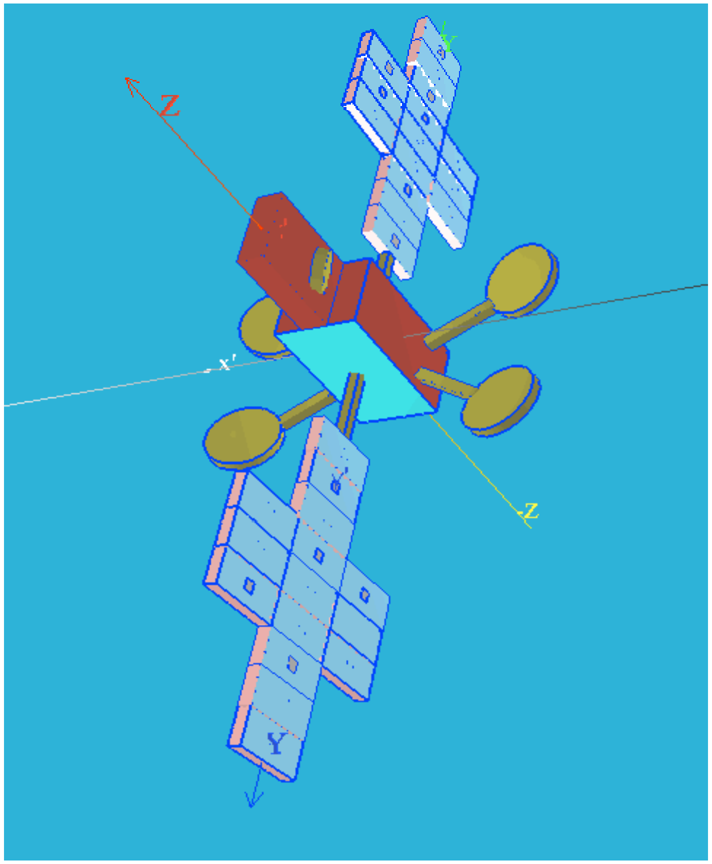


Baseline model (1A)

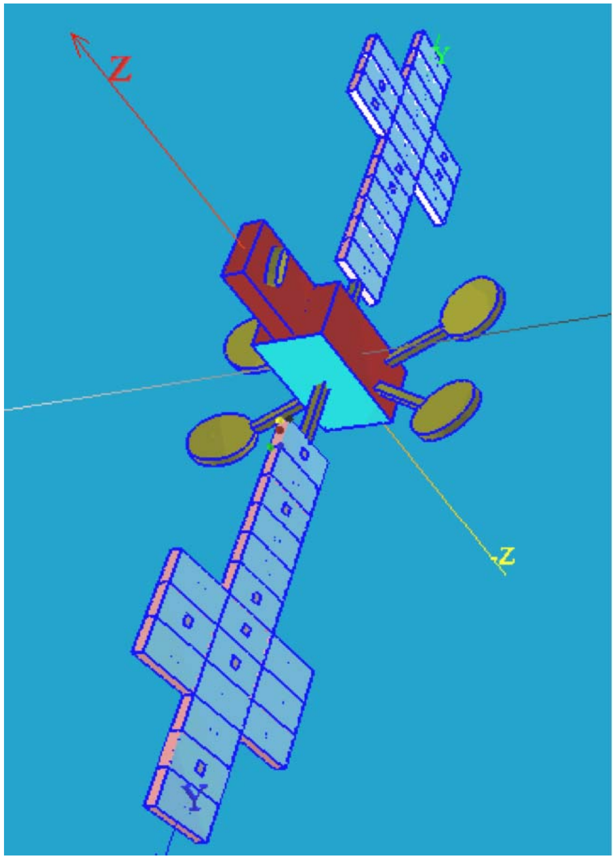
Satellite configurations

Model name	Solar Panels / wing	Side reflector	Mesh reflector	Tower reflector	Coverglass conductivity (1/Ωm)
1A	5	4	N/A	2	$2x10^{-12}$
1B	6	4	N/A	2	$2x10^{-12}$
1C	6	4	N/A	2	$2x10^{-12}$
XB	6	N/A	1	3	$2x10^{-12}$
2B	6	2	N/A	2	$2x10^{-12}$
1A’	5	4	N/A	2	$1x10^{-16}$

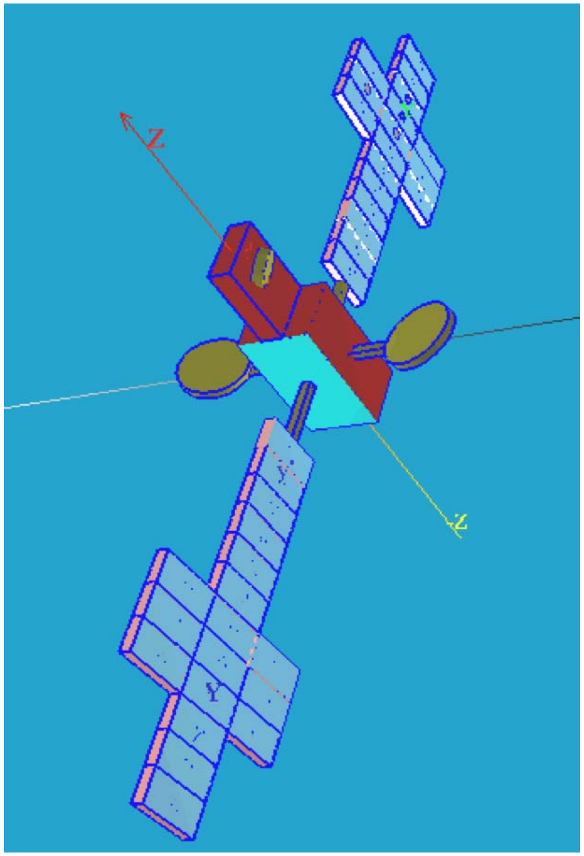
Satellite configurations



1A

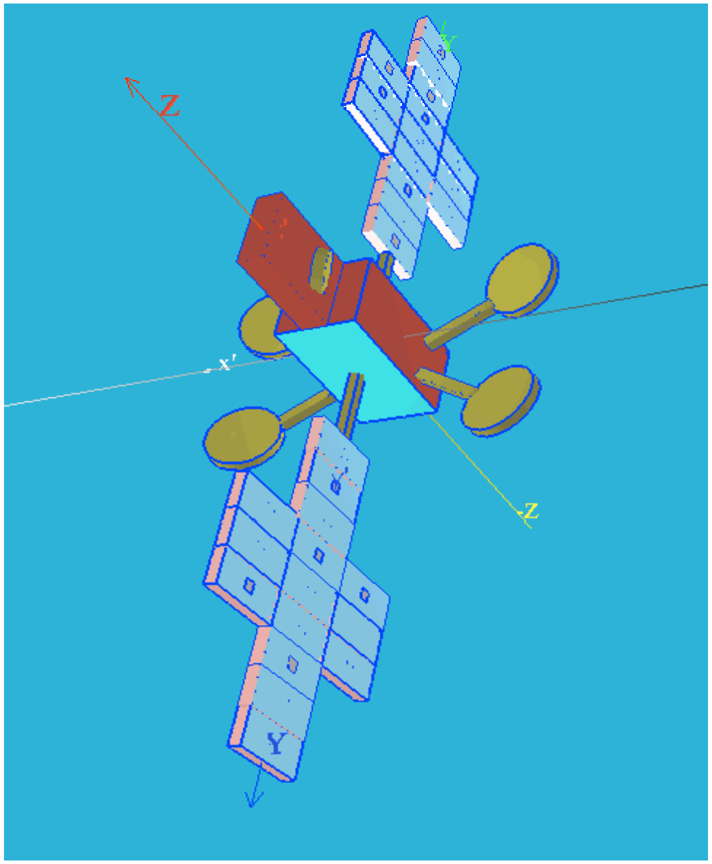


1B
(longer paddle)

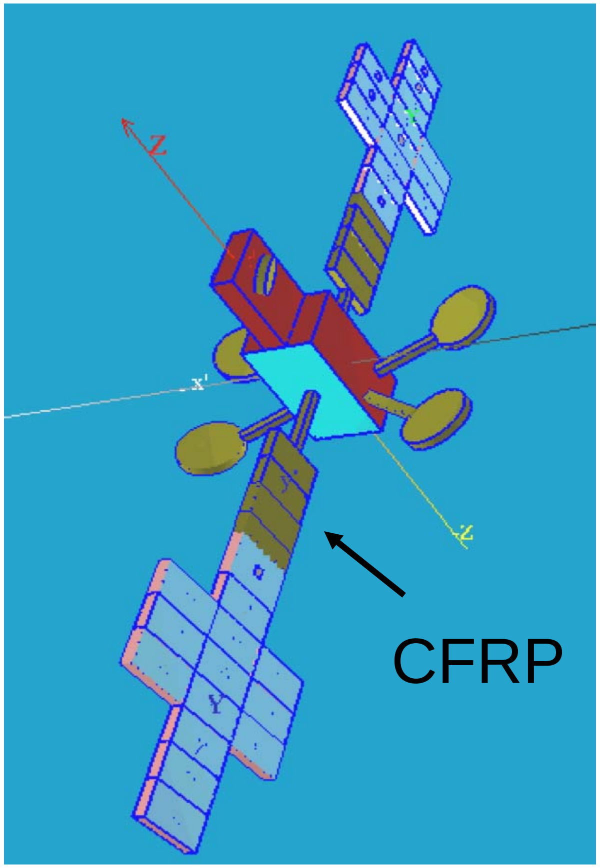


2B
(two antenna)

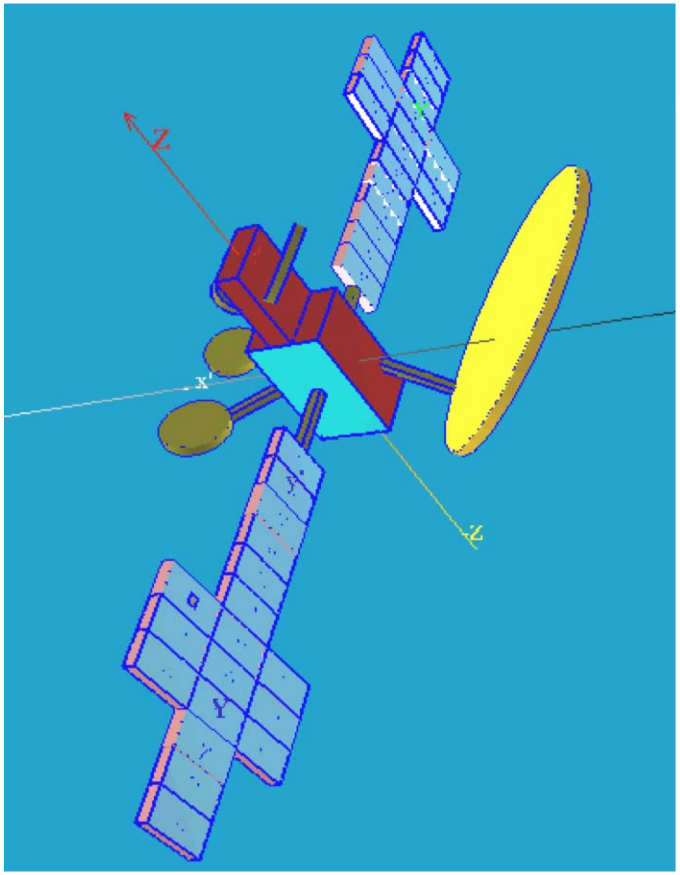
Satellite configurations



1A



1C



XB
(mesh antenna)

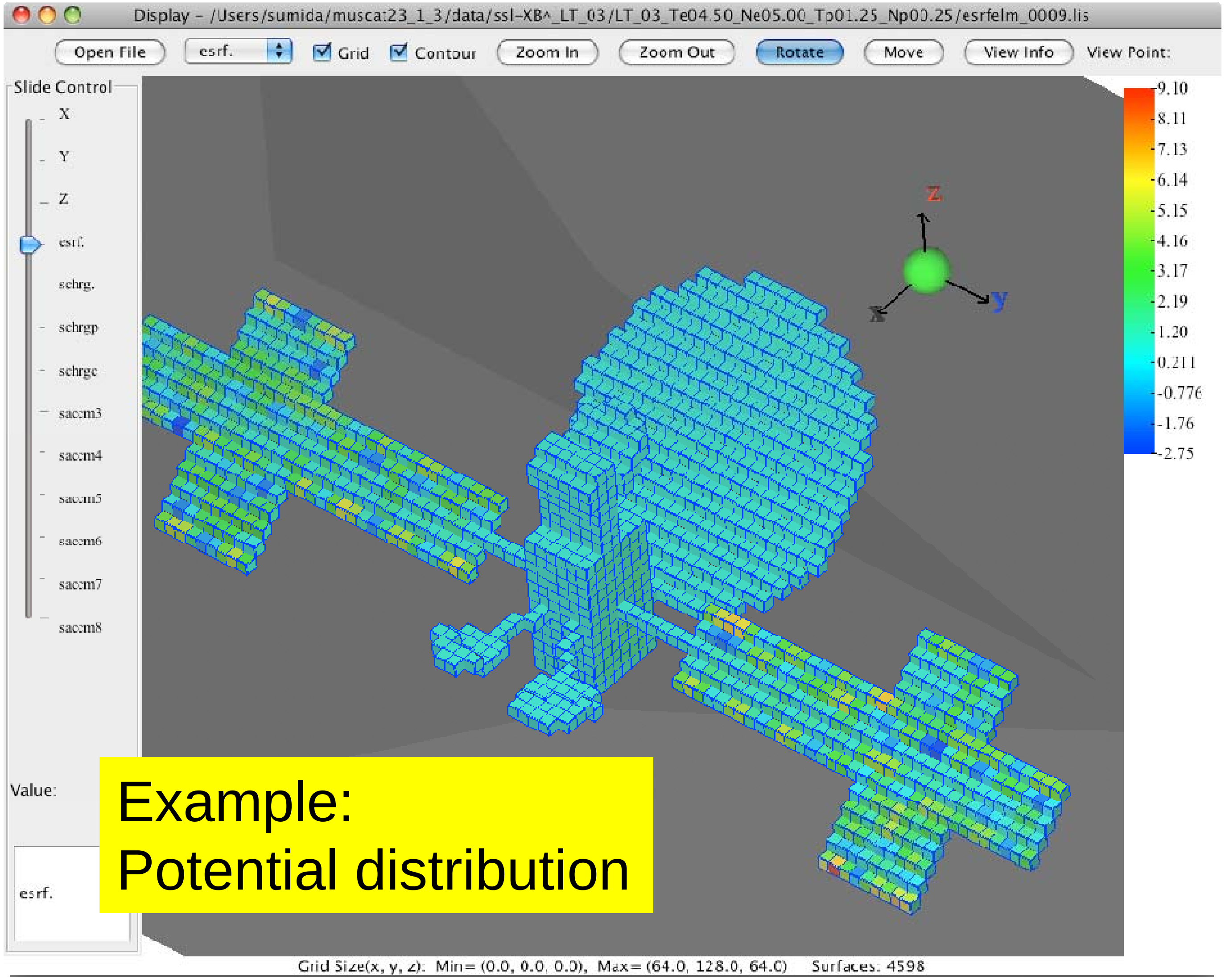
Charging environment

- Database of GEO plasma environment database
  – Based on LANL Magnetospheric Plasma Analyzer data
  – Electron density and temperature
  – Proton density and temperature
  – Identify all the possible combinations of the parameters with probability higher than 0.0001%
- To save the time, consider only the combinations with probability larger than 0.01% in the present work

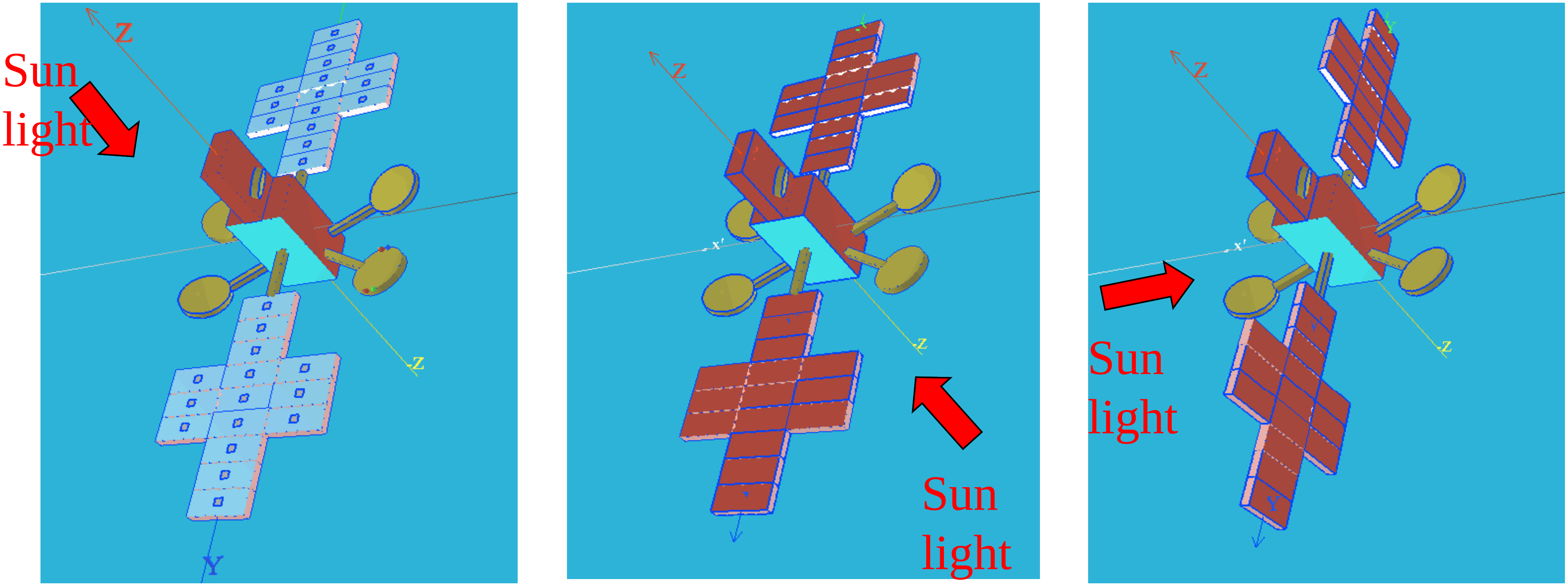
Simulation

Grid size : 0.3m, Computational domain: 64x128x64

Satellite chassis potential starts from -125V

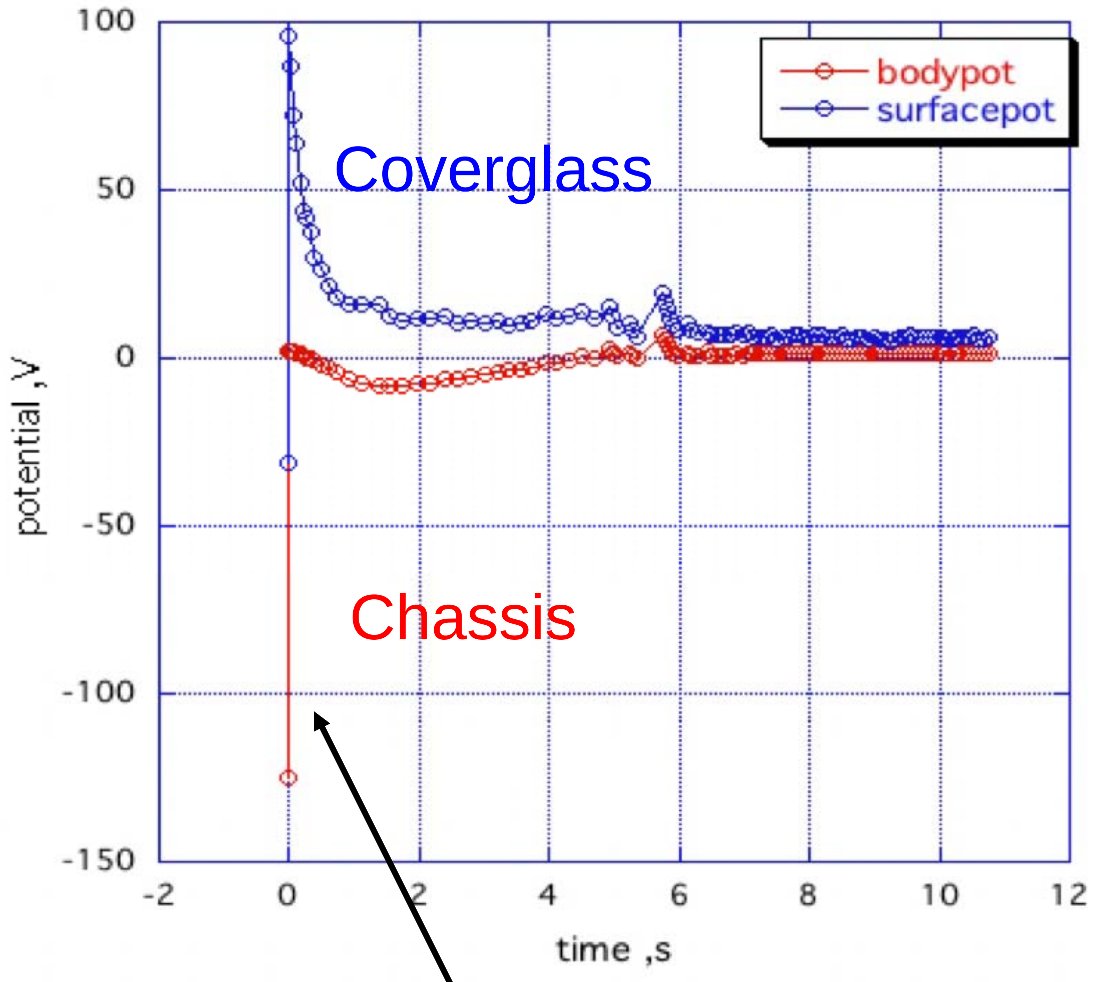


Local times



Run simulations for 8 local time zones

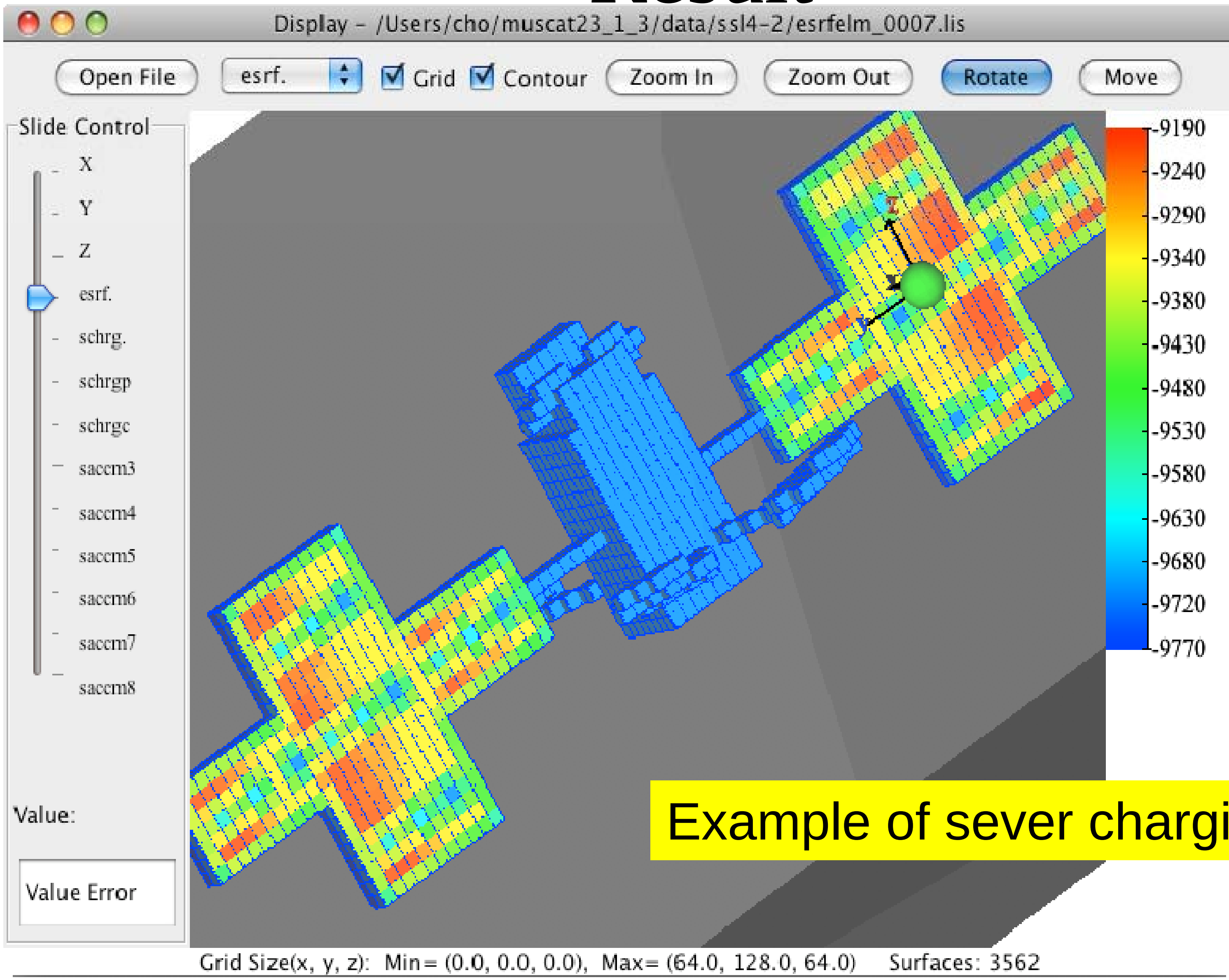
Result



Because of initial condition assuming -125V of chassis potential

- Majority of the cases show no charging

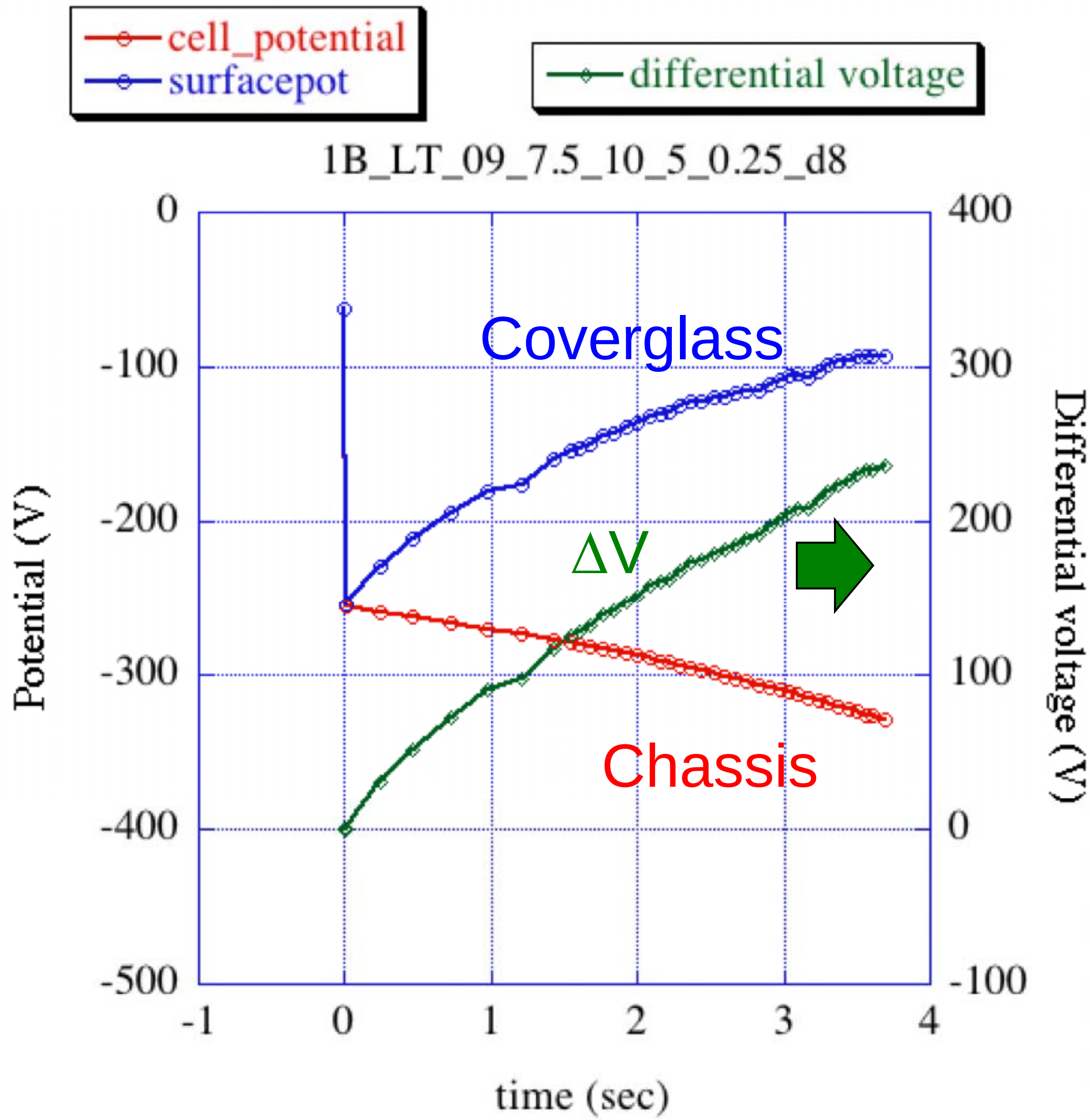
Result



Example of sever charging

Te=8000eV
Ti=1.6keV
Ne=$10^7 m^{-3}$
Ni=$10^7 m^{-3}$

Result



- Simulation stops when ΔV exceeds 400V anywhere on the satellite
- t_{chrg}=3.7 seconds
- N_e=10cm^{-3}, N_i=0.25cm^{-3}, T_e=7.5keV, T_i=5keV
- Probability of occurrence =0.01%
- t_{env}=3600×24×365.25×(1/8) ×(0.01/100)=395 seconds in one year
- Number of ESD in one year
  - N_{ESD}=395/3.7=107

Number of ESD events

- We divide the time into 8 local time zones
- For LT3 to LT21,

$$N_{ESD} = \frac{(\text{Probability}(\%)/100) \times 3600 \times 24 \times 365.23}{(\text{time to reach } \Delta V = 400)} \times \frac{1}{8}$$

- LT0 (non-eclipse)

$$N_{ESD} = \frac{(\text{Probability}(\%)/100) \times 3600 \times 24 \times 365.23}{(\text{time to reach } \Delta V = 400)} \times \frac{1}{8} \times 0.925$$

- LT0 (eclipse)

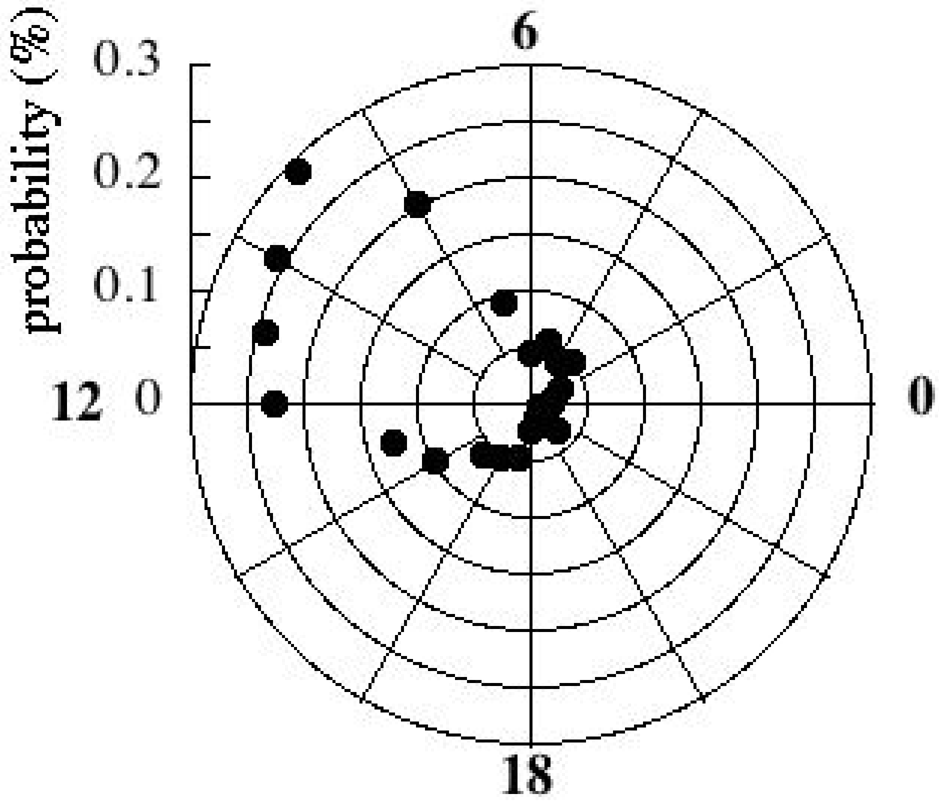
$$N_{ESD} = \frac{(\text{Probability}(\%)/100) \times 3600 \times 24 \times 365.23}{(\text{time to reach } \Delta V = 400)} \times \frac{1}{8} \times 0.075$$

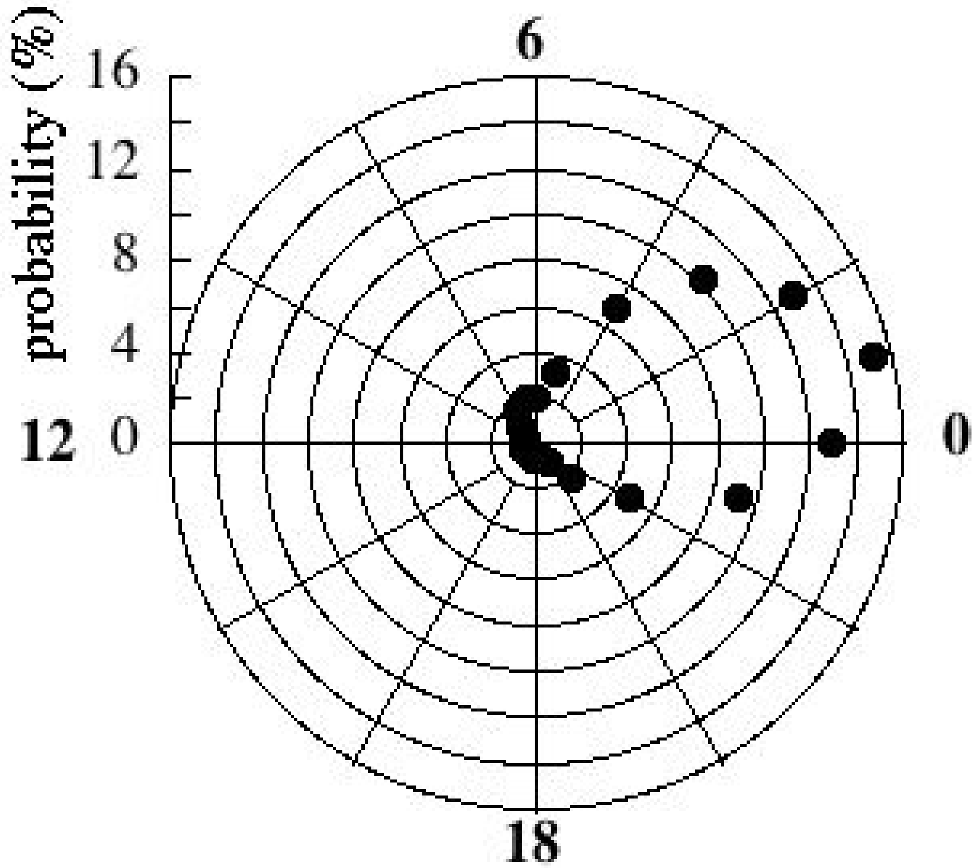
Number of ESD events

	LT0	LT3	LT6	LT9	LT12	LT15	LT18	LT21	Eclipse	Total
1A	70	484	645	1053	483	132	5	8	597	3476
1B	69	452	461	857	574	120	15	5	584	3138
1C	99	551	907	1681	631	631	16	15	1158	5688
XB	66	305	946	1227	530	54	23	33	427	3611
2B	67	464	405	775	468	102	5	3	480	2768
1A'	78	519	1054	1186	525	151	16	10	597	4137
WINDS (NASCAP)	152	320.5	478	482.5	487	291	95	129	556	2990

Number of ESD events in 1 year assuming ΔV_{th}=400V

Discussion





Probability of n_e>10cm^{-3}

Probability of T_e>3keV

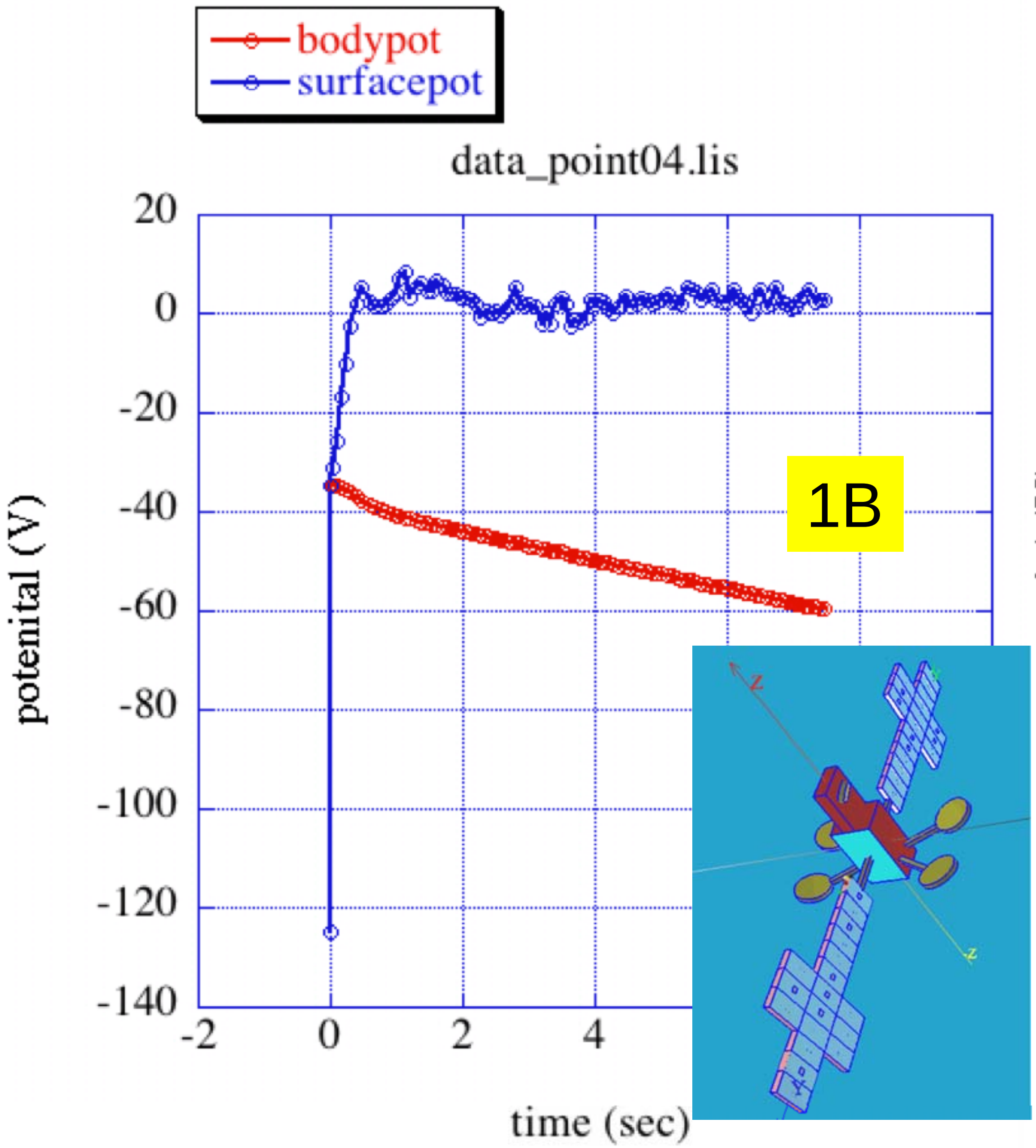
ESD occurs mostly between LT3~LT12 except eclipse

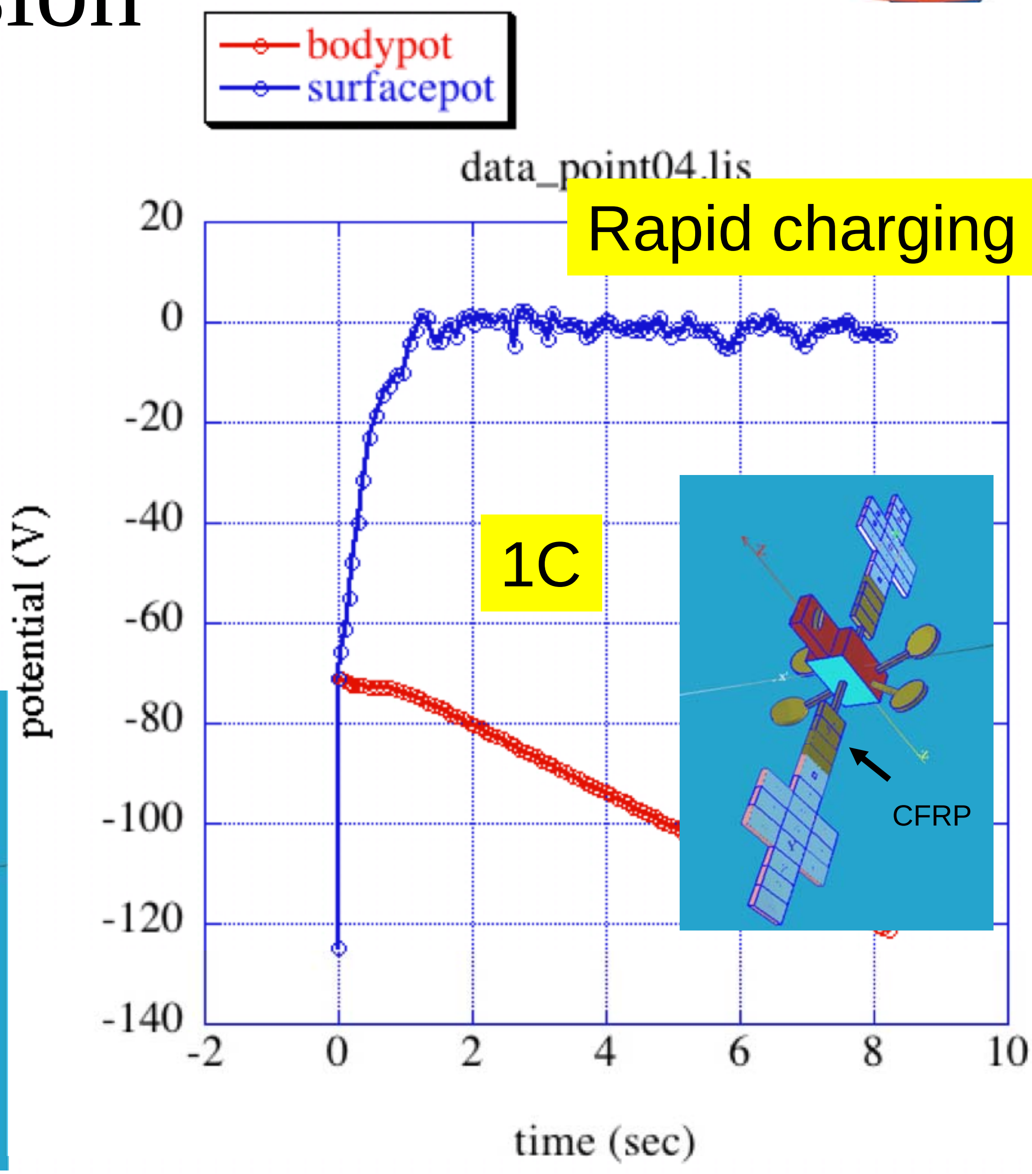
Discussion

Plasma parameters				Charging time (s)	
kTe(keV)	ne ($10^6 m^{-3}$)	kTi (keV)	ni($10^6 m^{-3}$)	SS/L 1A' (MUSCAT)	WINDS (NASCAP)
7.5	5	5	0.25	13.48	20.00
7.5	5	10	0.25	12.49	20.00
7.5	10	5	0.25	5.74	8.00
7.5	10	10	0.25	5.91	8.00
10.5	5	5	0.25	4.64	12.00
10.5	5	10	0.25	4.61	12.00
10.5	10	10	0.25	4.50	6.00

- Material properties data for SS/L and WINDS are the same
- Whether a satellite charges or not depends on the environment
- How quickly it charges depends on the capacitance
- WINDS coverglass capacitance 1.8X SS/L

Discussion





Because of more conductive area, 1C charges more rapidly

Discussion

	LT0	LT3	LT6	LT9	LT12	LT15	LT18	LT21	Eclipse	Total
1A $2x10^{-12}$ (1/Ωm)	70	484	645	1053	483	132	5	8	597	3476
1A' $1x10^{-16}$ (1/Ωm)	78	519	1054	1186	525	151	16	10	597	4137

- Difference of coverglass conductivity affects little

Conclusion (1/2)

- Number of ESD events have been estimated using
  - MUSCAT simulation
  - LANL GEO plasma environment data
- Total number of ESD events in 15 years
  - 45,000 to 90,000 assuming ESD threshold voltage of ΔV_{th}= 400V
  - □ ΔV_{th}= 1800V from ESD test on GaAs/InGaP/Ge triple junction solar cell coupons
  - The total number of ESD events for 15 years is 10,000 to 20,000
- Typical high power GEO satellite has 300 to 500 strings
  - 20 to 70 ESDs per string in 15 years
- These numbers assume ΔV_{th} does not change over 15 years

Conclusion (1/2)

- Results similar to the previous work on a different satellite with NASCAP/GEO
  - As long as the satellite is charged, the charging time is determined by coverglass capacitance
  - As long as the plasma environment and the spacecraft material are similar, the result becomes similar.
  - The difference due to the satellite geometry resulted in difference only by a factor of two.