宇宙放射線環境と衛星内部帯電障害

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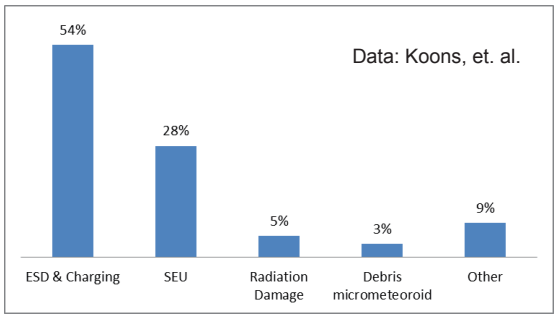
Statistics of satellite anomaly caused by the space environment

Koons, et. al., Aerospace Corp. Report, TR-99, 1999

Satellite Anomaly Analysis: 1973-1997

"ESD(Electro Static Discharge) & Charging" and "SEU(Single Event Upset)" are the most frequently cited causes of on-orbit anomalies



Satellite Digest News (SDN)

95 anomalies have been reported for the period of 1997 - 2009 in the geostationary satellite orbit. 32(about 33%) cases of these anomalies were due to the space environment except the operation mistake and the design error.

Choi, et. al., SPACE WEATHER, VOL. 9, 2011

Local time and seasonal dependence of anomaly above 32 cases

21:00LT～9:00LT: 72%

9:00LT～21:00LT: 28%

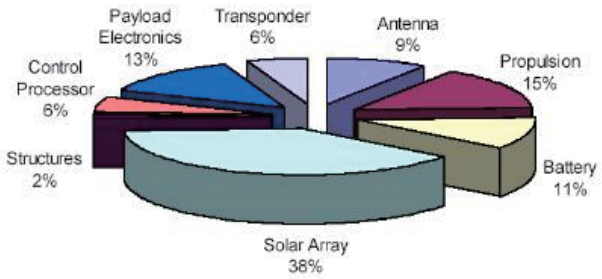
Most of the geostationary satellite anomaly occurred at midnight and in the morning sector . They conclude that the surface charging with the particle injected from the magneto tail along with the magnetic storm is the main causes of anomalies at GEO.

Statistics of insurance payment on orbit of commercial satellite

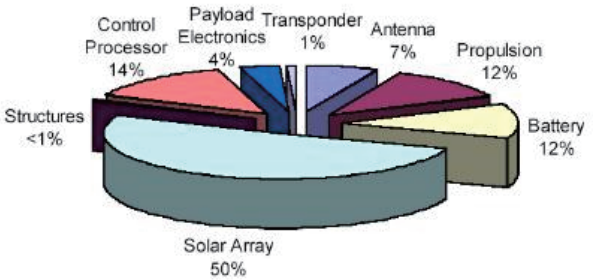
Frost & Sullivan analyzed the on-orbit performance of the major commercially available satellite buses and considered the strengths and weaknesses of their manufacturers in order to determine which satellite bus (or platform) is more reliable.

According to the value of claims by anomaly type, "Solar Array" accounts for 50%. Mitigation of solar array anomaly is very important.

Number of Insurance Claims by Anomaly Type



Value of Claims by Anomaly Type



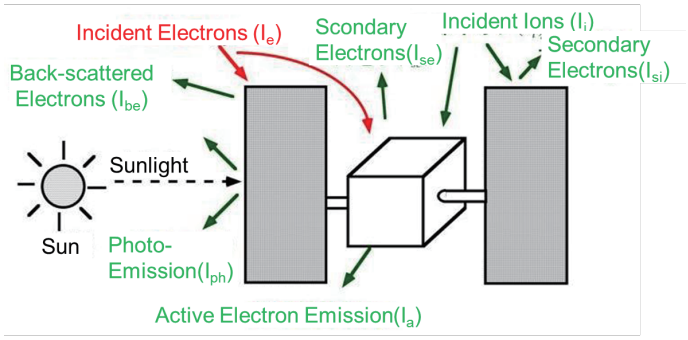
source: Frost & Sullivan and Airclaims

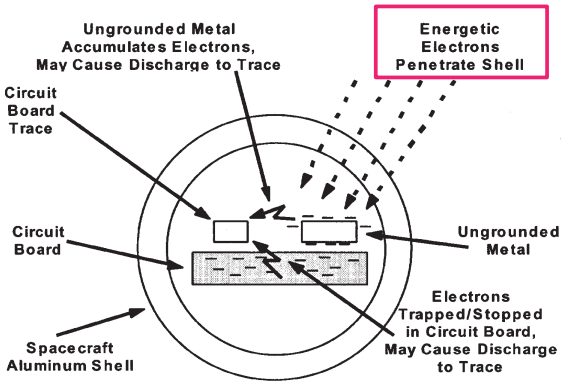
Commercial Communications Satellite Bus Reliability Analysis
http://www.lr.tudelft.nl/index.php?id=29218&L=1

Surface charging and internal charging

Surface charging

Internal charging





NASA-HDBK-4002

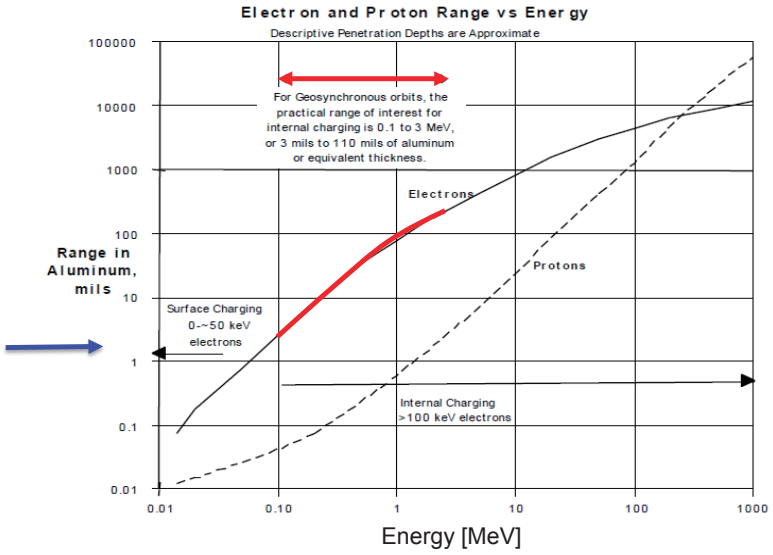
Internal Charging

- Internal charging is caused by the electrons, which exceed the energy of 0.1 MeV at the radiation belt, that penetrate the outer wall of the spacecraft.
- Internal charging occurs at the circuit board, coaxial cable or dielectric.
- Charging at the conductor which is not grounded.
- If this charging level exceeds the voltage proof, discharge will occur and causes a malfunction at the weak point, such as the defect of material or needle shape projection.

Internal charging at GEO

The energy range of electrons at the radiation belt which may cause the internal charging is,
Above 0.1MeV (below this energy, electron cannot penetrate the typical wall of spacecraft)
Less 3.0MeV (above this energy, flux is not enough to cause the charging)

Typical satellite wall thickness



Electron/Proton Penetration depth in Aluminum

NASA-HDBK-4002

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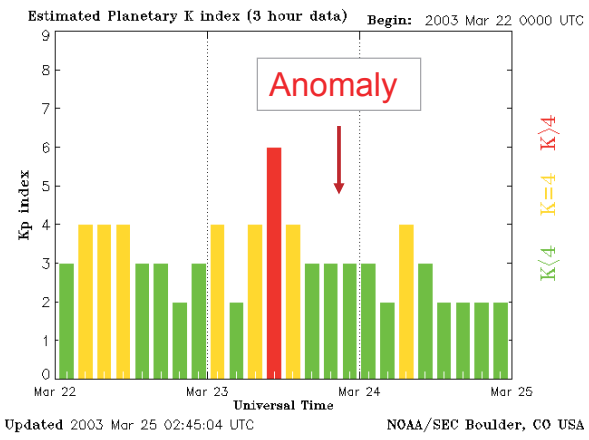
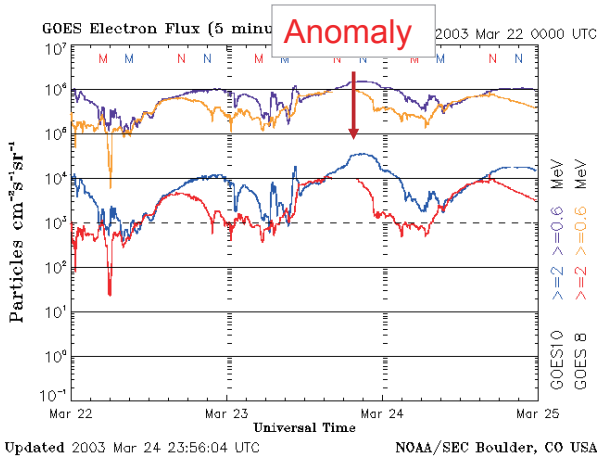
Example of satellite anomaly

- Earth Sensor Assembly (ESA) of Data relay satellite (DRTS) on the geostationary orbit has shifted to the redundant system (sensor A -> B) on March 23, 2003.
- Anomaly was caused by the increase of the noise of ESA.



Estimated Kp



GOES high energy electrons

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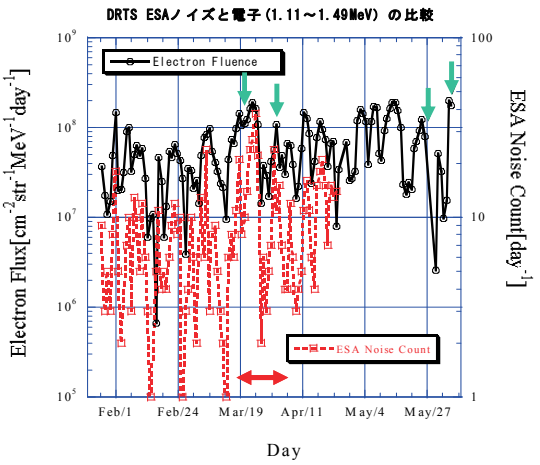
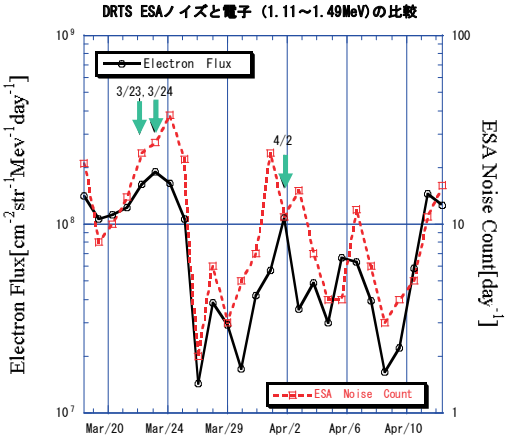
Relationship between the ESA noise and high energy electrons

- Space environments were analyzed, and it is found that there is a relationship between the noise counts and electron flux (1.11-1.49MeV).
- => probably caused by internal charging

DRTS ESA noise vs. electron flux (1.11-1.49MeV)



2004 February～March

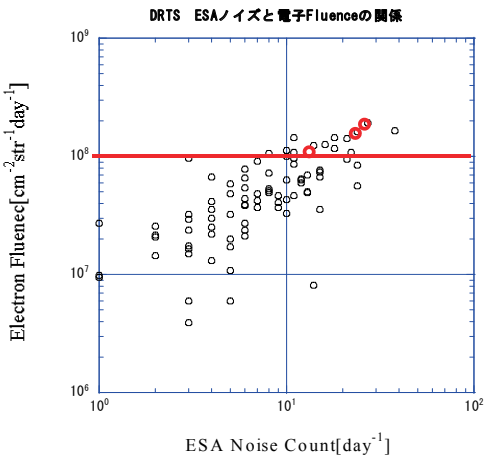


2004 3/20-4/10

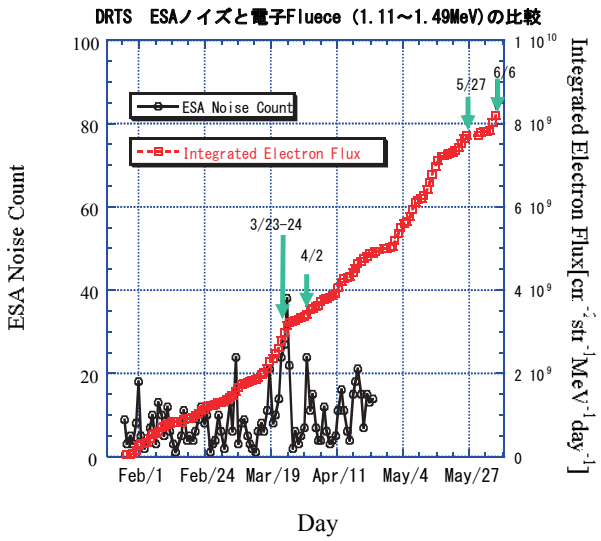
Threshold level of electron flux related anomaly occurrence

- Anomaly occluded above the electron flux of 10^8($cm^{-2}str^{-1}day^{-1}$). (left figure)
- Also, this phenomena occurred when the flux rapidly increase.(right figure)

ESA Noise vs. electron fluence [1 day]



ESA Noise vs. integrated electron flux



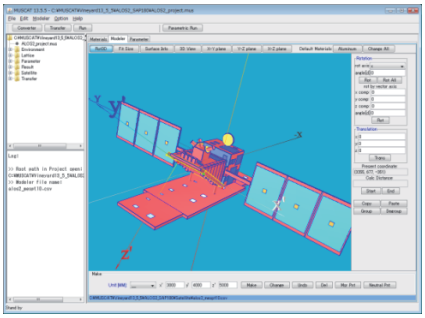
MUSCAT (Multi-Utility Spacecraft Charging Analysis Tool)

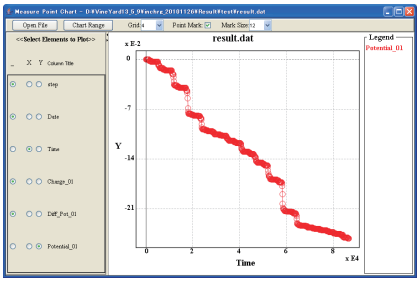
MUSCAT is the charging analysis tool for satellite design. The development of MUSCAT commenced in 2006, and was completed with cooperation from the researcher in 2009.

Surface charging
The computer code used with MUSCAT is a hybrid of PIC (Particle In Cell) and PT (Particle Tracking), aiming to calculate the charged analysis within half a day.

Internal charging
Using Monte Carlo simulation for penetration of high energy electrons.

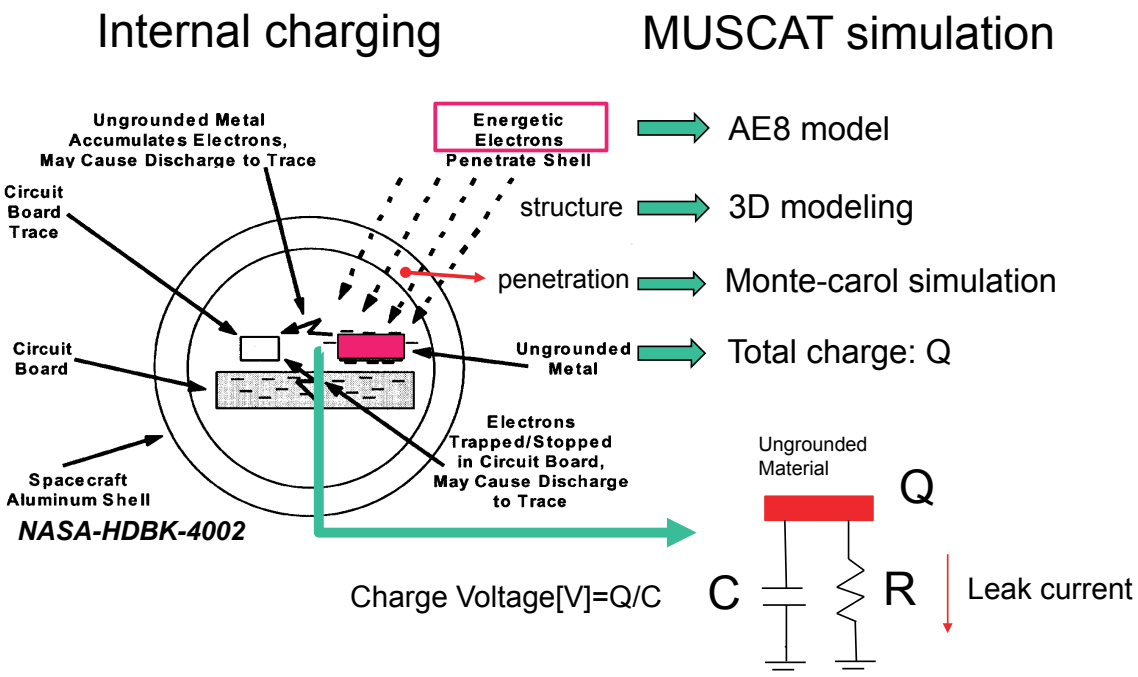
GUI





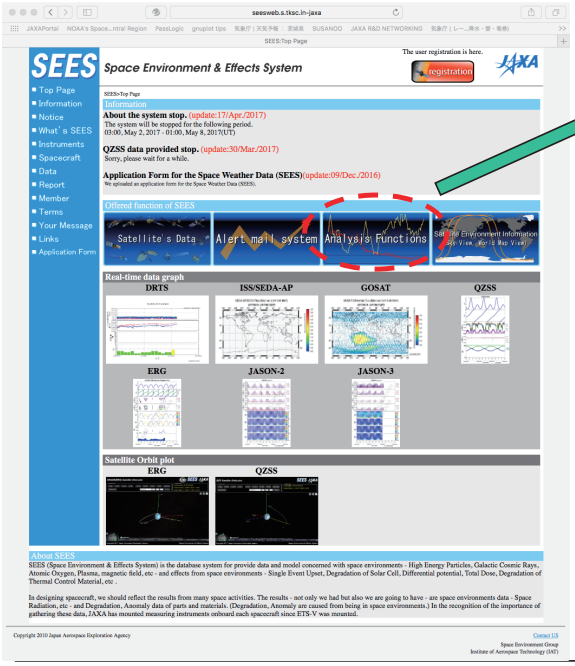
MUSCAT is available from MUSE (MUSCAT Space Engineering Co., Ltd.).

MUSCAT internal charging simulation

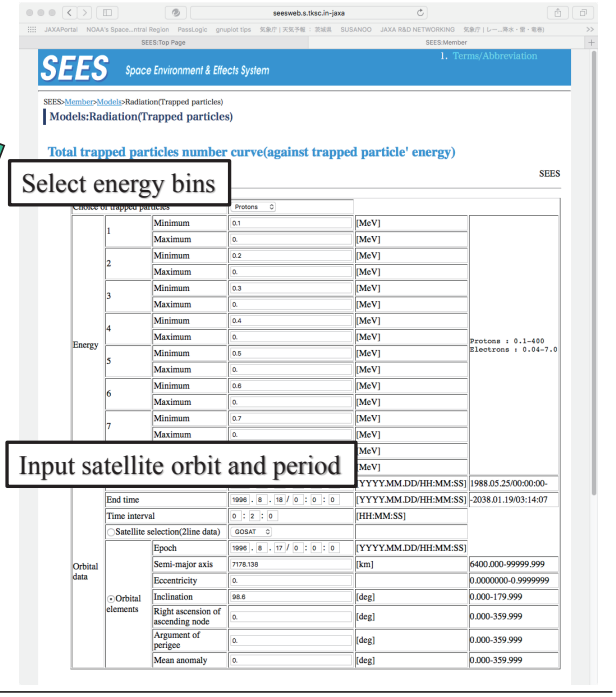


MUSCAT (Input of space environment)

Space Environment & Effects System
http://sees.tksc.jaxa.jp



AE8 (radiation belt electron model) calculation



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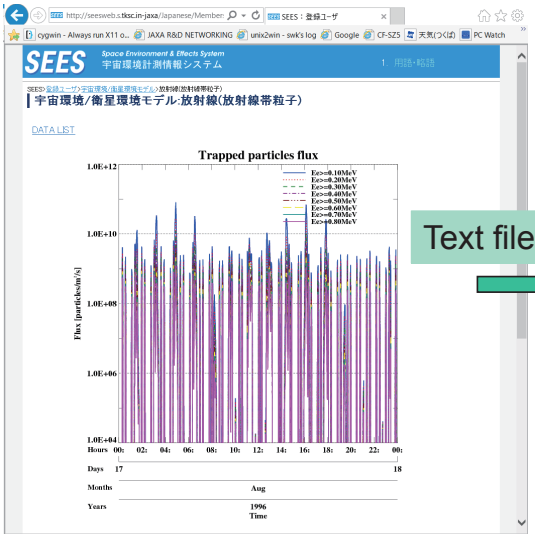
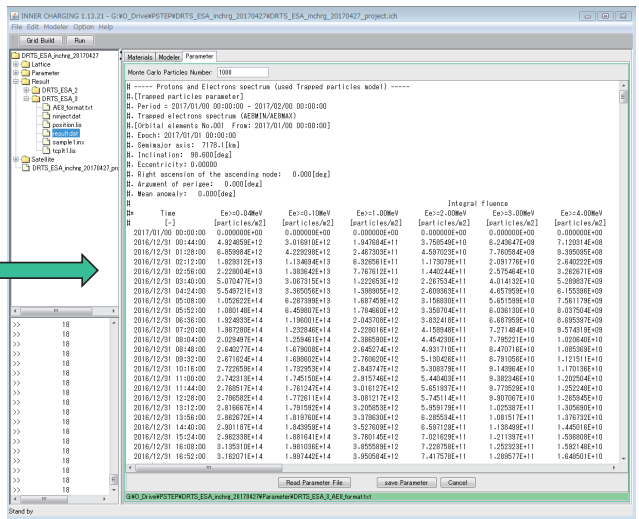
MUSCAT (Input of space environment)

Calculate the electron flux using SEES according to the satellite orbit with AE8 model.

Input the electron flux trend to the MUSCAT





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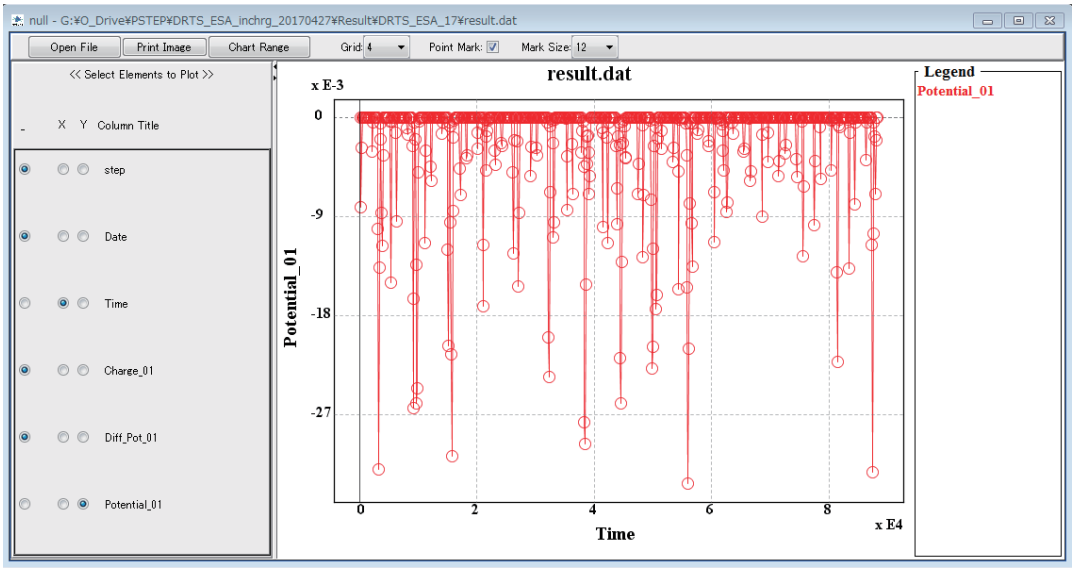
Example of internal charging calculation

Potential trend of the sample

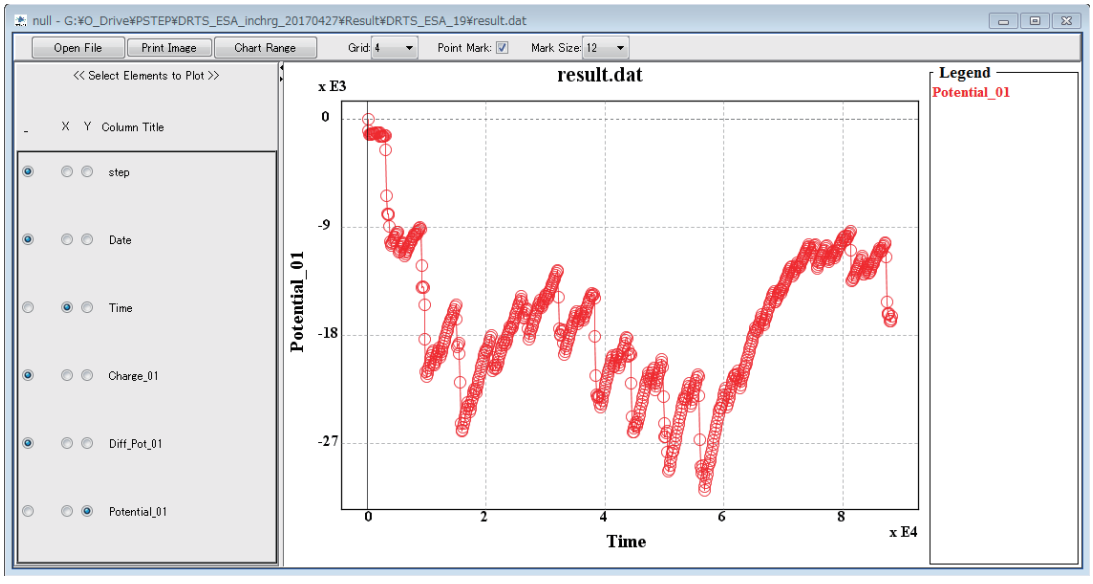
Case 1
Charge ≒ Leak (small resistance)



Example of internal charging calculation

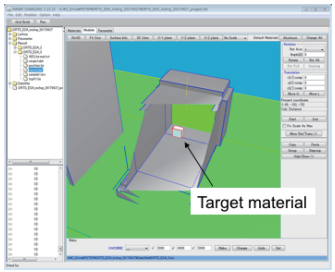
Potential trend of the sample

Case 2
Charge > Leak (large resistance)

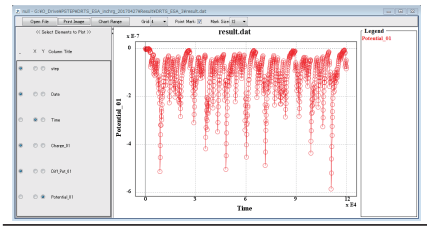


Concept of SECURES for internal charging

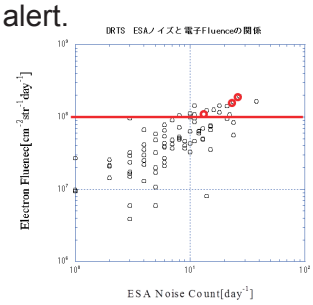
1)Customer selects the weak point of internal charging for the operating satellite.



2)Simulate the charging level using MUSCAT.



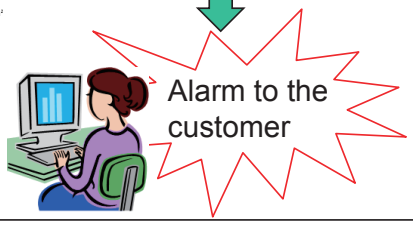
3) Clarify the relationship between charging level and space environment.
And decide the threshold level of high energy electrons for alert.



Threshold level

4) PSTEP A03 output
High energy electron prediction

Exceed threshold level!



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