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Surface Charging

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British Antarctic Survey
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Introduction

- ~ 50 % of the space system anomalies related to space environments due to charging (internal or surface)

- Surface charging related to low energy electrons and ions (< 100 keV) that deposit their charge on covering materials
  - Plasma – Spacecraft interactions prevail (collection and emission)
  - ‘Absolute charging’ defines potential difference bw SC and plasma
  - ‘Differential charging’ defines the voltage between adjacent materials
  - Large absolute charging may induce large differential charging that may induce electrostatic discharges (ESDs)

- Objectives
  - Define ‘severe’ and ‘extreme’ environments leading to ESD risks
  - Propose updates of mitigation guidelines wrt to current practices

- Outline
  - Charging assessment by numerical simulation
  - ‘Severe’ environments
  - ‘Extreme’ environments
  - Mitigating surface charging

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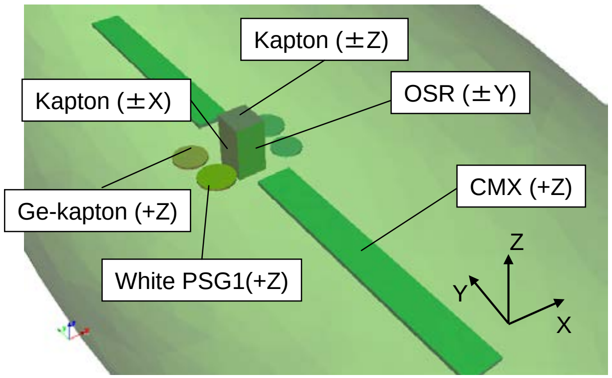
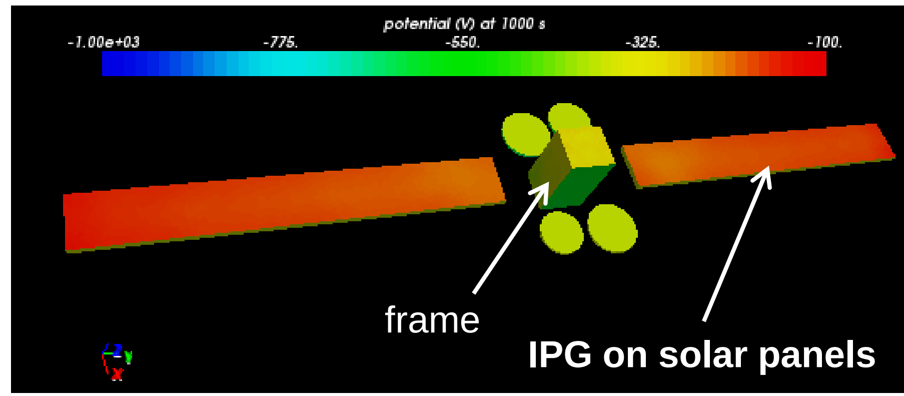
Charging assessment by numerical simulation

- Spacecraft Plasma Interaction Software: open source, www.spis.org
- 3D Telecom spacecraft model



Mateo-Velez, Theillaumas et al. 2015



- Material properties from literature and from ONERA measurements (see **Radiation Experiments and New Materials**)
- ESD risk indicator
  - Inverted Potential Gradient (**IPG**): negative conductor nearby a less negative insulator, known to generate primary ESDs
  - Representative of major risk on solar arrays: secondary arcing
  - Identify 'severe' and 'extreme' environments → SPACESTORM project in synergy with CNES R&D

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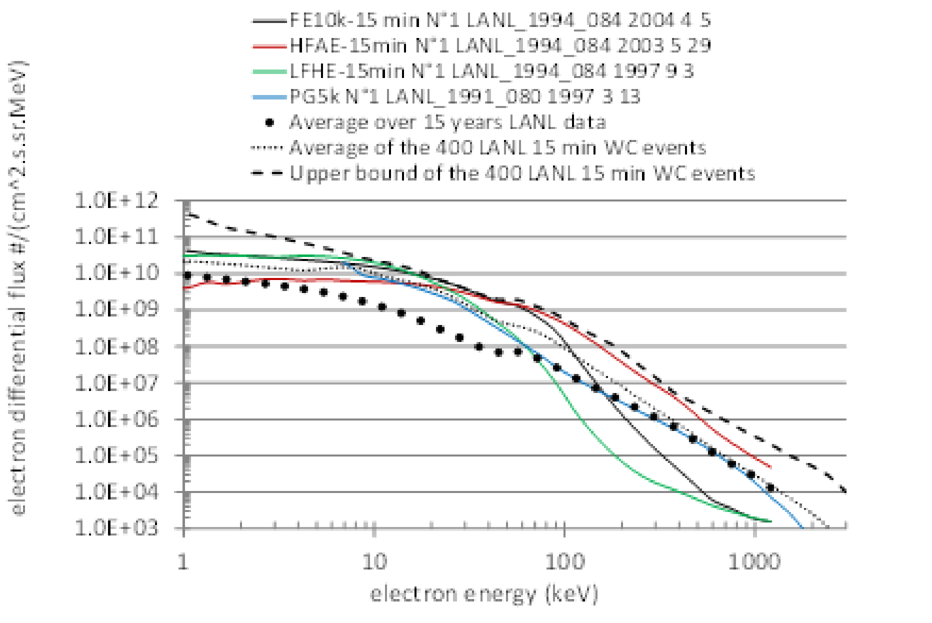
‘Severe’ environments from LANL spacecraft

- ONERA/CNES R&D activities : analysing 15 years of LANL data at GEO
  - e-/p+ : 100 eV up to 4-6 MeV
  - Three criteria used to classify 15 minutes average electron fluxes
    - Largest fluxes above 10 keV ……………………………………….April 5th, 2004
    - Combined large flux above 200 keV and low flux below 50 keV ….May 29th, 2003
    - Combined low flux above 200 keV and large flux below 50 keV ….Sept 3rd, 1997
  - One criterion used as a function of spacecraft potential
    - Longest period of time (tens of minutes) with potential exc. -5 kV…March 13th, 1997
  - 400 hundreds events identified in total (probably some others to come)



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‘Severe’ environments from LANL spacecraft

- The 400 LANL events have been consolidated by additional information
  - Good correlation with NOAA/POES 1% and 0.1% exceedance flux levels (see **‘1 in XX Year Events**’)
  - Solar wind and geomagnetic indices

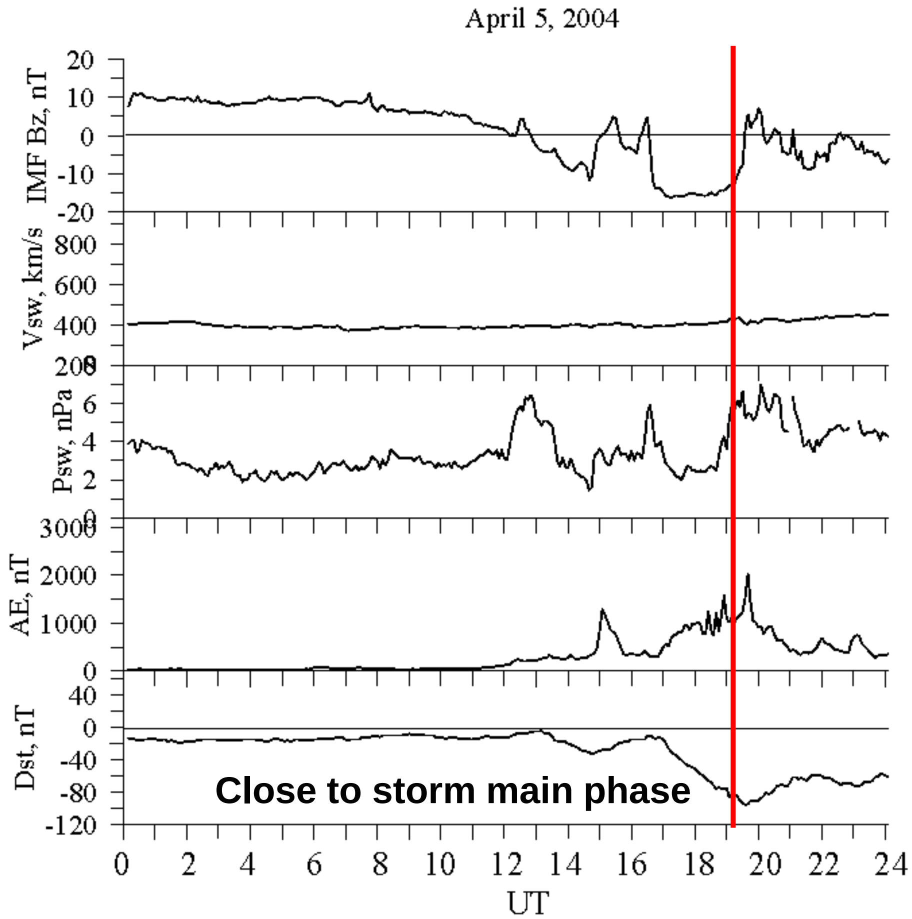
    ~50% storm, ~50% isolated sub-storm

→ LANL Data base is robust

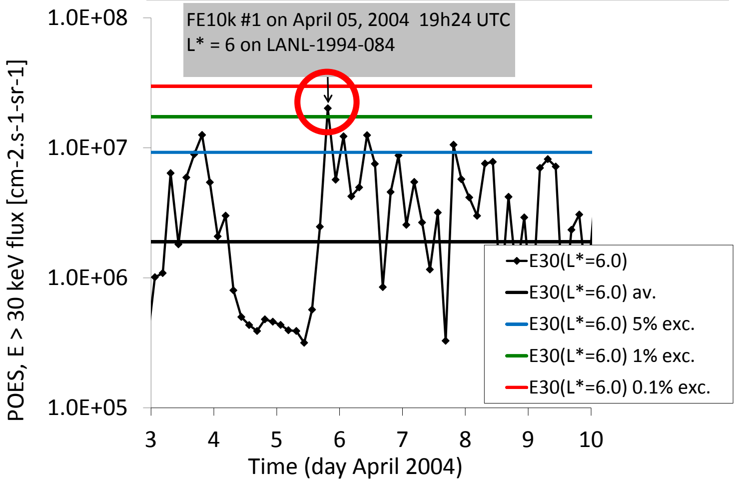
- ‘**Low Energy Electrons**’ IMPTAM model used to
  - Compare 4 LANL worst events at GEO : good agreement on electrons
  - Unique tool to predict radiation belts < ~ 200 keV where few measurements are available
  - Focus on GNSS orbits L = 4.6

‘Severe’ environments from LANL spacecraft

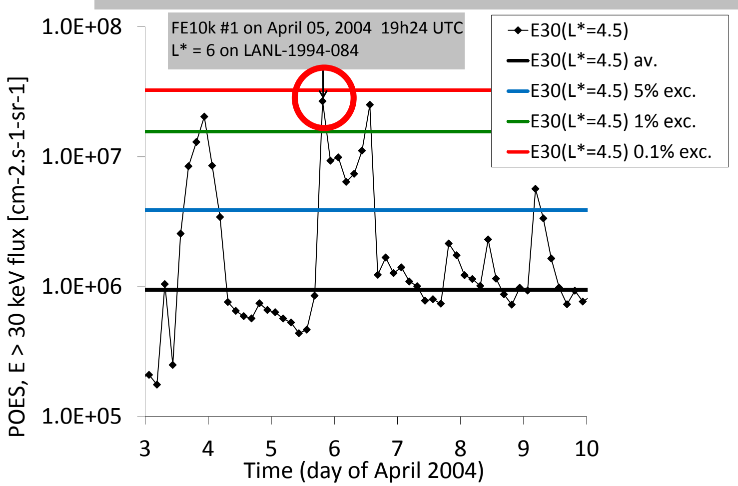
- Example of event on April 5th, 2004



>1% exc. flux on POES at L* = 6



~0.1 % exc. flux on POES at L* = 4.5



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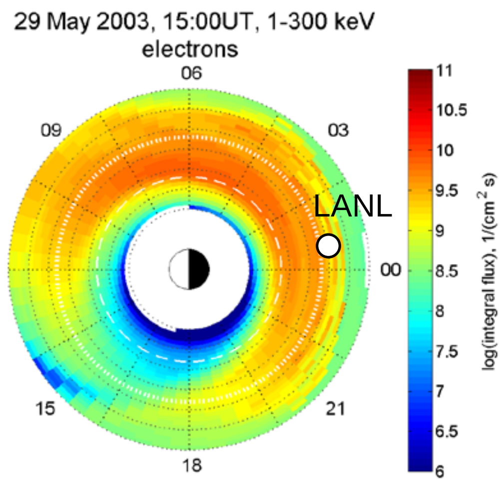
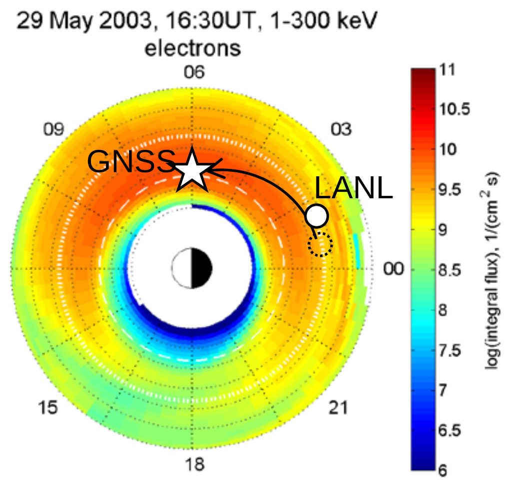
‘Severe’ environments from LANL spacecraft

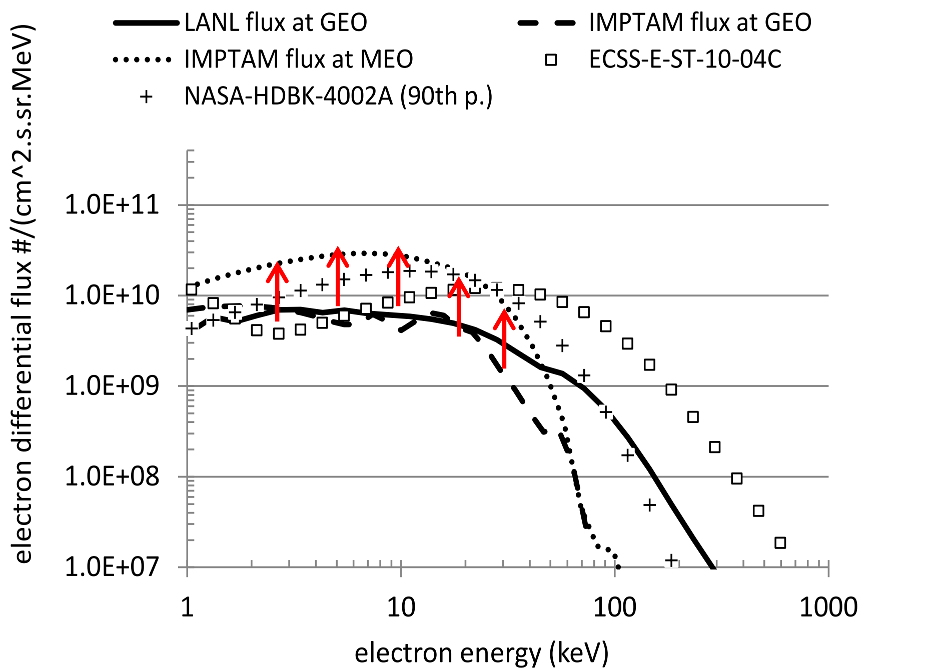
- Example of event on April 5th, 2004

@ LANL event



Worst GNSS:
@LANL event +
90 min

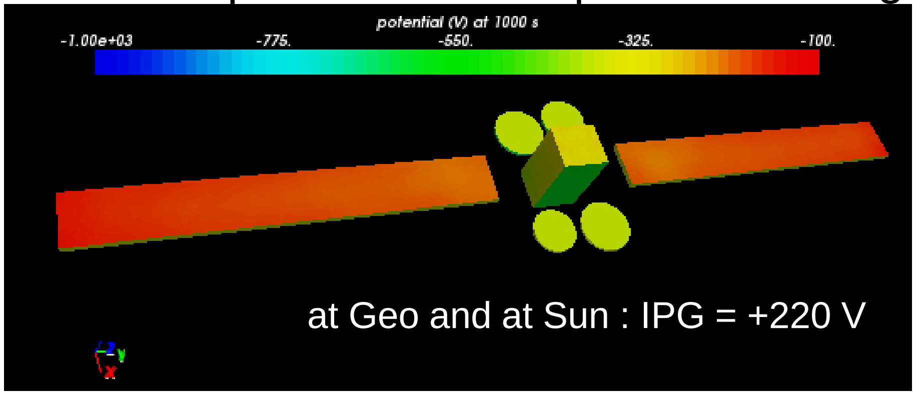


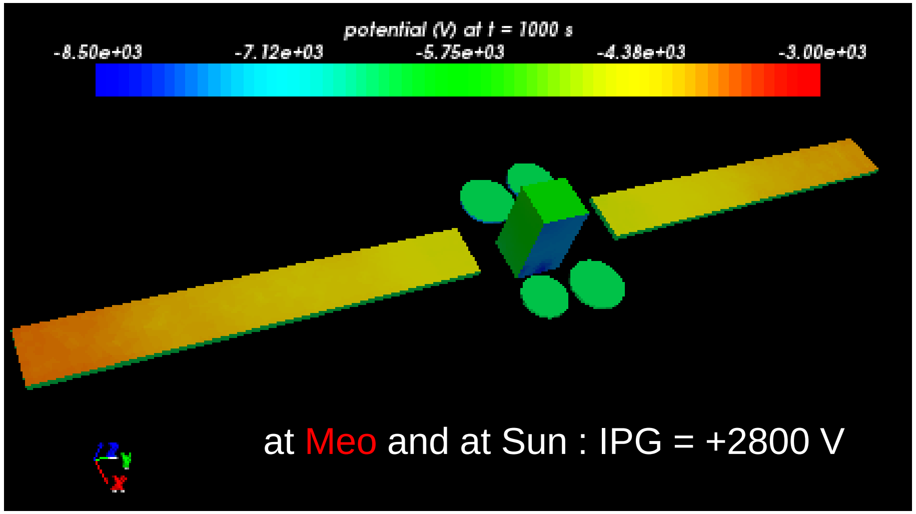


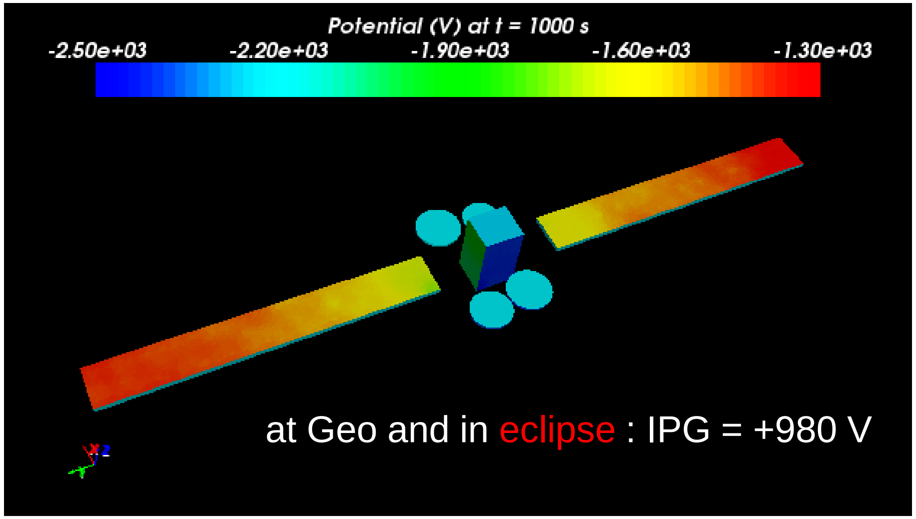
Prediction @MEO is about one order of magnitude larger than data and prediction @GEO

‘Severe’ environments from LANL spacecraft

- Example of Telecom spacecraft charging under the env. of April 5th, 2004







Simulations show increased risks

- at MEO
- in eclipse
- at MEO + eclipse

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Recommendations on ‘Severe’ environments from standards

- ECSS and NASA standards worst-cases are very conservative at GEO
- At GEO, we recommend to use
  - ECSS-E-ST-10-04C: double maxwellian fit of SCATHA April 24th, 1979 event, which overestimated the actual data
  - NASA-HDBK-4002A: 90th percentile GEO
- At GEO, we suggest to use
  - LANL events: April 5th, 2004; May 29, 2003; Bastille day; Halloween…
  - Tri-maxwellian fit of SCATHA April 24th, 1979
- At MEO, we recommend to use ECSS worst-case
- Worst charging situations combine severe environments above and eclipse
  - Recommend charging assessment at eclipse exit
  - Combined effect of cold materials and return of photoemission process

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Nowcast surface charging indicator

- Additional statistical analysis of the 15 years of LANL data also showed a good agreement between spacecraft charging and 10-50 keV electron fluxes

- Used to define risks levels at GEO (See **Risk Indicators Website)**
  - e- $Flux_{10\text{-}50keV} > 10^8$ $cm^{-2}.s^{-1}.sr^{-1}$: High Risk Level
  - e- $Flux_{10\text{-}50keV} > 4\times10^7$ $cm^{-2}.s^{-1}.sr^{-1}$: Significant Risk Level
  - e- $Flux_{10\text{-}50keV} > 1.5\times10^7$ $cm^{-2}.s^{-1}.sr^{-1}$: Moderate Risk Level
  - Otherwise: Low Risk Level

Risk Indicators

	Internal Charging	Surface Charging	Ionising Dose	Solar Cells
GOES East	1	1	1	1
GOES West	1	1	2	1
Giove-A	1	Not available	1	1
Slot Region 8,000 km	1	Not available	3	4

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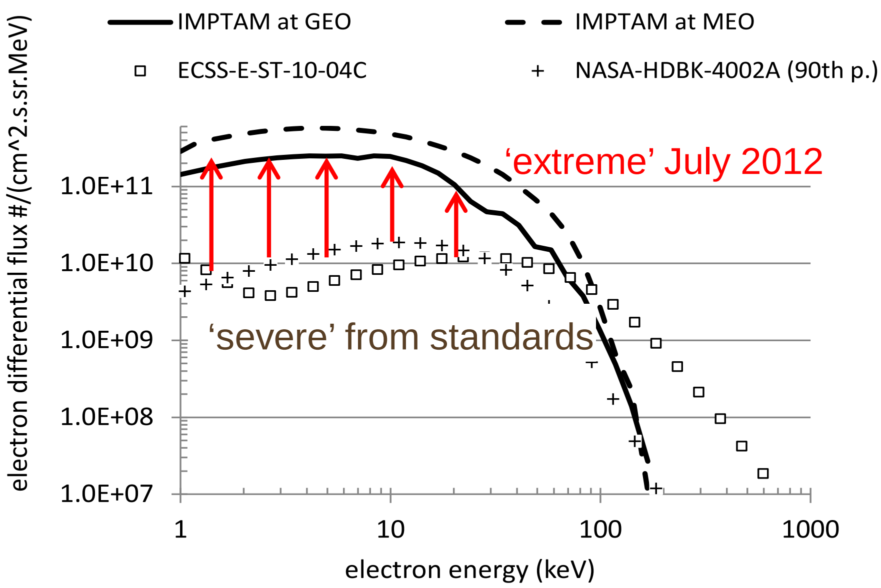
‘Extreme’ environments

- July 23-24, 2012 extreme event
  - Extremely fast CME that missed the Earth
  - IMPTAM simulation to assess ‘extreme’ magnetosphere fluxes
  - Initial phase: Maximal electron flux (<100 keV) would be about one order of magnitude larger than LANL, NASA and ECSS worst case… during minutes
  - Main phase/Recovery phase: electron loss due to stretched B-field lines; probably no additional surface charging



  - IPG of +2600 V at GEO and +3200 V at MEO within 20 seconds: **huge ESD risk**
  - Recommend to use July 23-24, 2012 for surface charging in ‘extreme’ conditions

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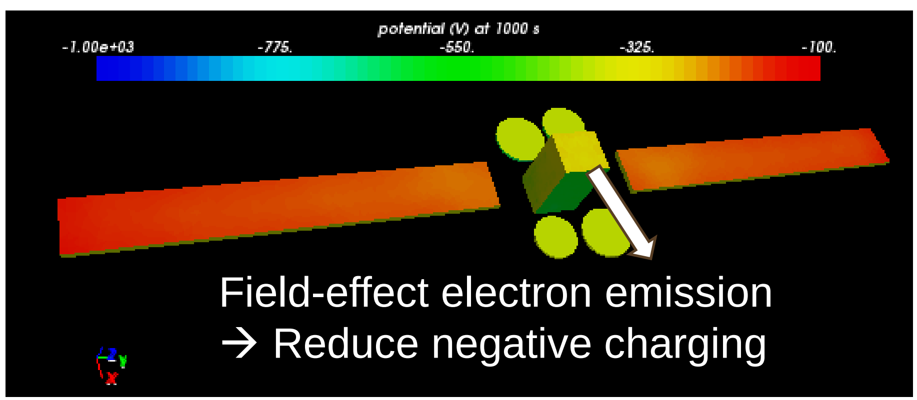
Mitigating the risk

- ECSS and NASA guidelines to avoid ESD and detrimental effects (in brief)
  - Bound/ground surface metallic parts
  - For non-conducting surfaces, if feasible, use thin conductive covering layers such as ITO
  - Protect electronic equipment against EMC induced by external ESD
  - Protect power systems against secondary arcing, especially solar arrays

- Alleviate negative charging : Counterbalance electron collection by electron emission using field-effect emission devices



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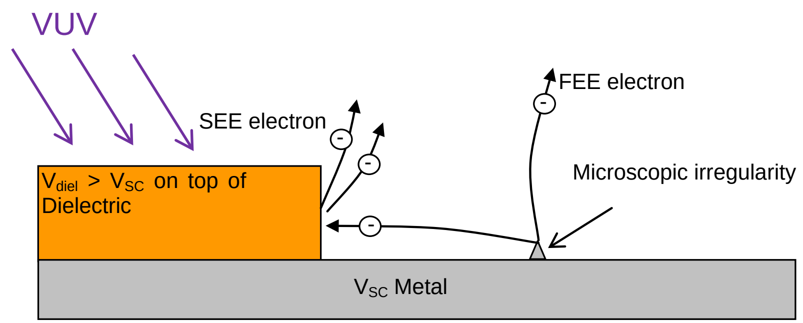
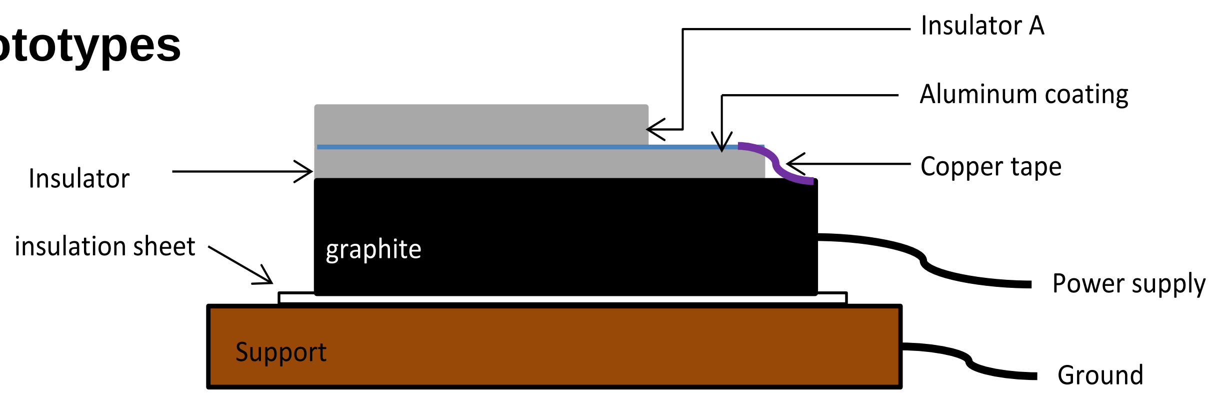
Passive electron emitter

1. **Propose a general design**



2. **Build and test prototypes**



3. **Assess efficieny in spacecraft charging environment**

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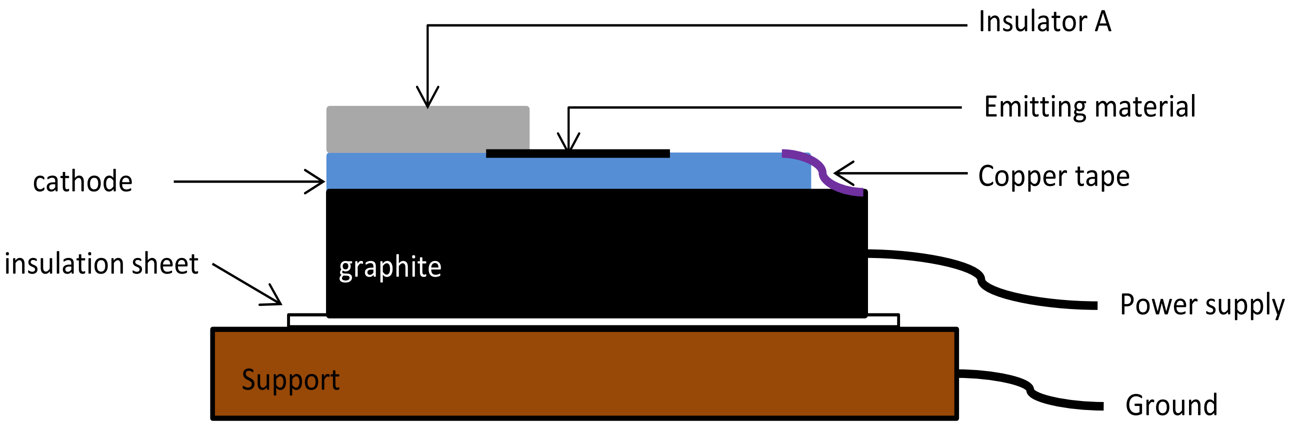
Samples

- Anode
  - Dielectric material charged passively and freely by environment
  - Better if covered with appropriate thin layer

- Cathode
  - Nano technology material
  - Increases the microscopic electric field and field-effect emission
  - Active area ~ 0.1 cm^2.



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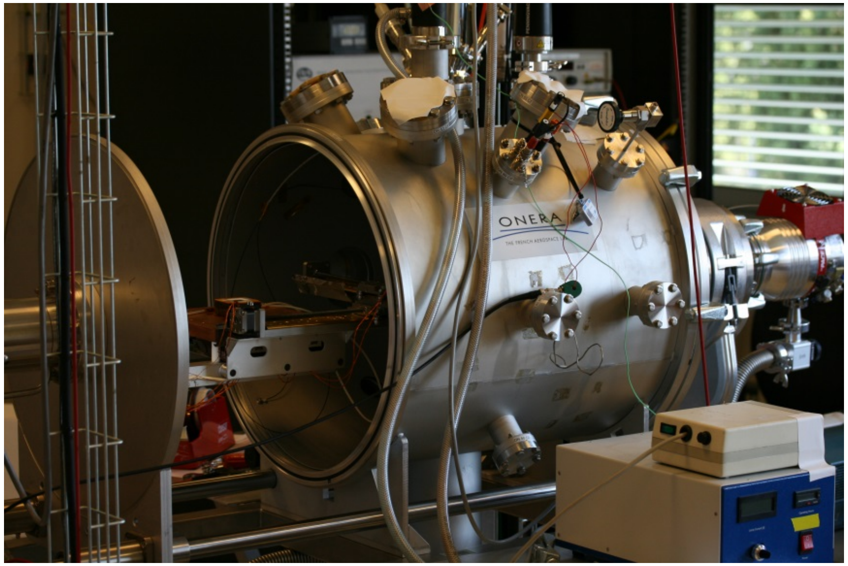
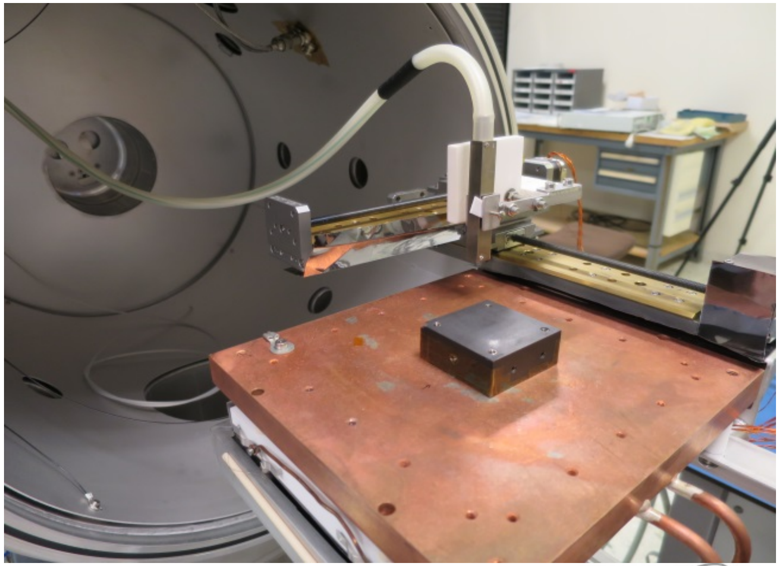
Test facility

- Testing in a new ONERA vacuum chamber called PHEDRE
  - 1e-7 mbar
  - 55*60 cm
  - Heating/Cooling support
  - Charging by VUV and/or electron beam
  - Complete DAQ system (X-Y surface potential, ESD monitor, electron emission, etc)





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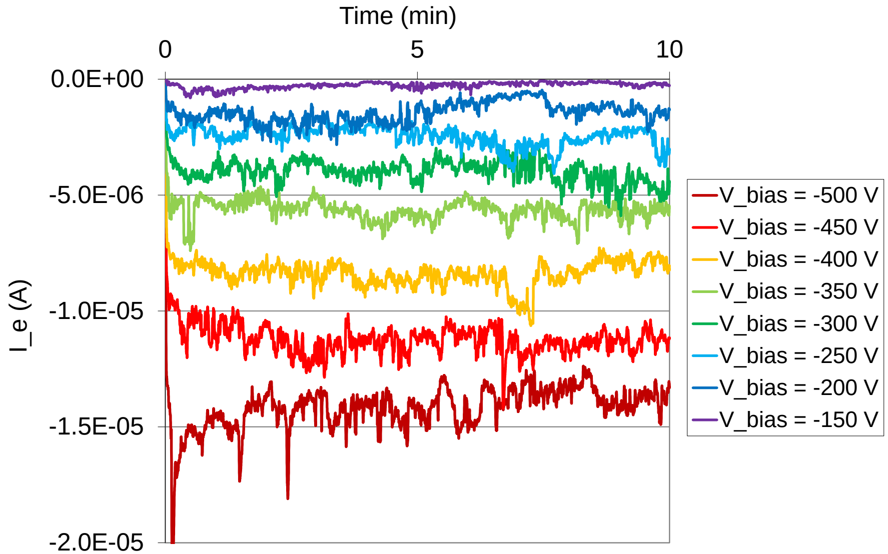
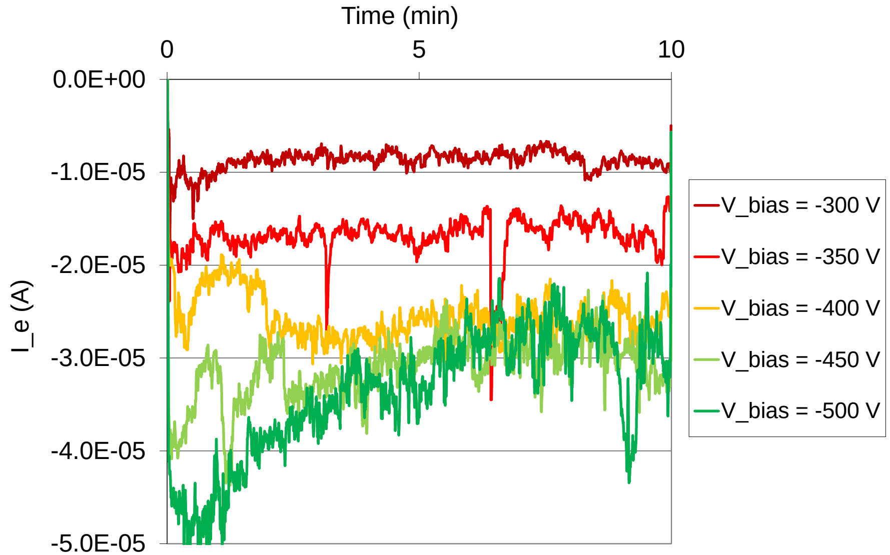
Passive emission assessment

- Current-voltage assessment
  - High impedance circuit (10 MΩ): -14 ± 1 µA at V_bias = -500 V
  - Low impedance circuit (1 MΩ) : -29 ± 5 µA at V_bias = -500 V
  - Saturation around -30 µA



10 MΩ



1 MΩ

- Field-effect current of 10-30 µA (10^3 times the charging photocurrent !)
- No ESD was triggered within several hours of operation

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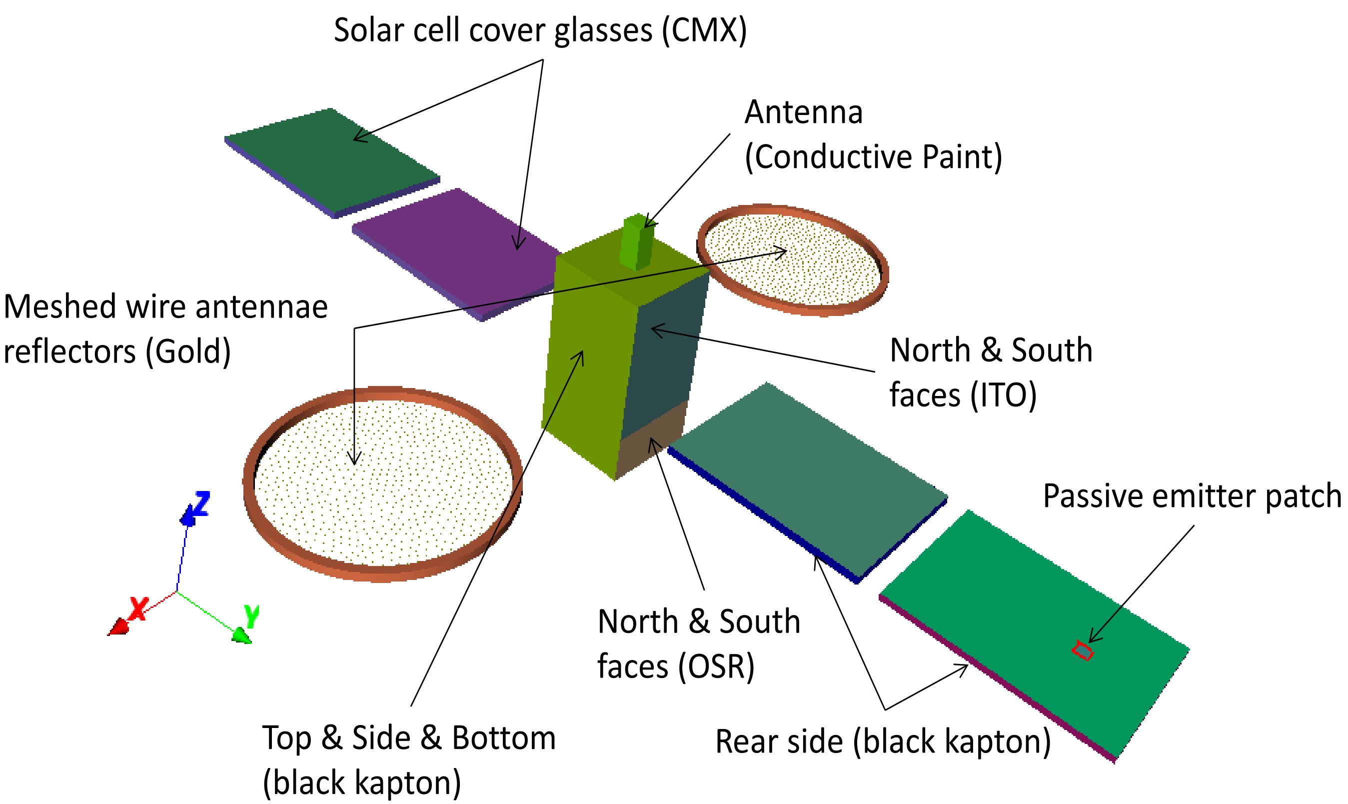
Spacecraft charging assessment

- Assessment of efficiency at spacecraft level with SPIS



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Spacecraft charging assessment

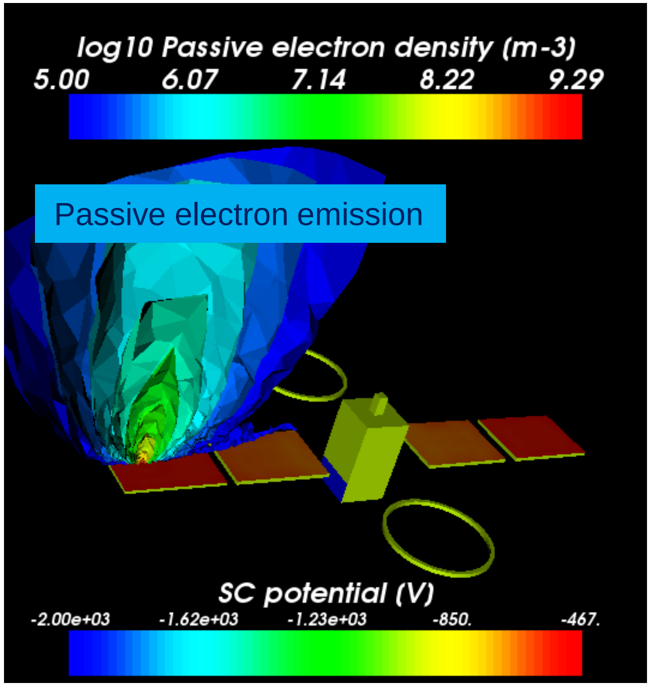
- Emitters to be located close to the extremity of solar arrays (from ESA/ONERA activity on Passive electron emission Co 4000105753/12/NL/KML)

- Emitted current as a function of local IVG, from experimental results

- ECSS worst case environment at Sun
  - Frame : - 6 000 V
  - IVG : + 3 000 V

- At Sun with 1 emitter (estimated area ~1 cm^2)
  - Frame : - 5 500 V
  - IVG : + 2 200 V

- At Sun with 10 emitters (estimated area ~10 cm^2)
  - Frame : - 950 V
  - IVG : + 500 V



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Summary - Contribution to European Space Industry

- 'Severe' environments to be used within ECSS WG on E-HB-20-06A
  - For a spacecraft surface charging estimation to be conservative at GEO, it is recommended to use ECSS or NASA 90th worst-case; with possibility to use LANL worst-cases and ECSS suggested adaptations
  - To be conservative at MEO, it is recommended to use ECSS worst case
  - Consider eclipse exit as a worst scenario
- 'Extreme' conditions such as the event on July 23, 2012 that missed the Earth would increase the ESD risk by a factor of five wrt ECSS worst-case, both at GEO and at MEO
- Additional mitigation techniques need to be implemented
  - This project showed the feasibility to use field-effect : important inputs to ESA plans to manufacture passive electron emitters
  - Further efforts are required to manufacture testable and qualifiable prototypes (need to improve cathode material and anode mounting)

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Internal to Spacestorm

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