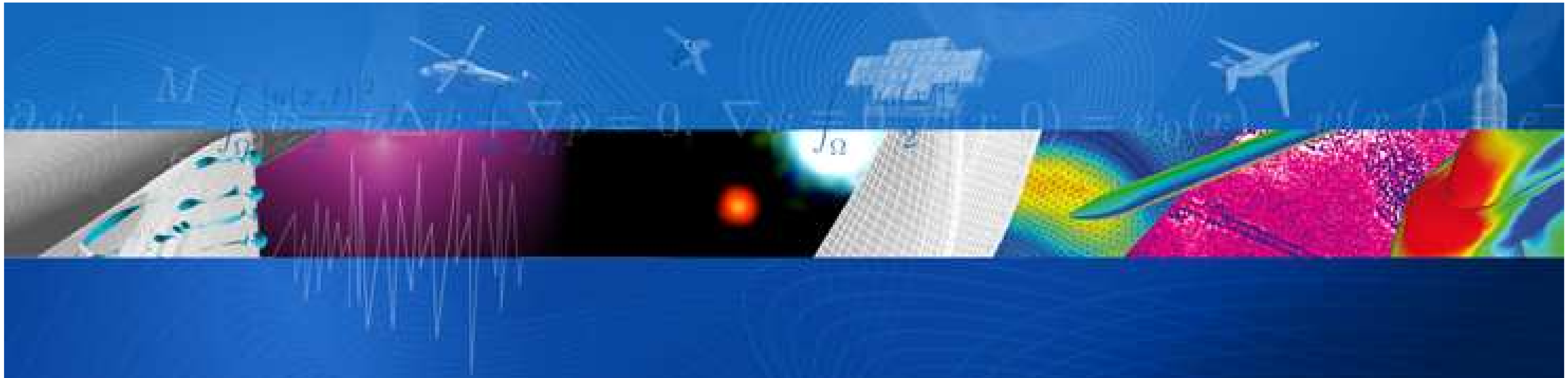

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Predictive discharge study

SPIS workshop, SPINE meeting, September 28 2009

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Objective

- In the frame of ESA funding
  - Develop and validate a numerical tool for the prediction of ESDs on spacecraft solar panels
- Outline
  - Charging at GEO
  - Discharge process
  - Modelling efforts

Charging

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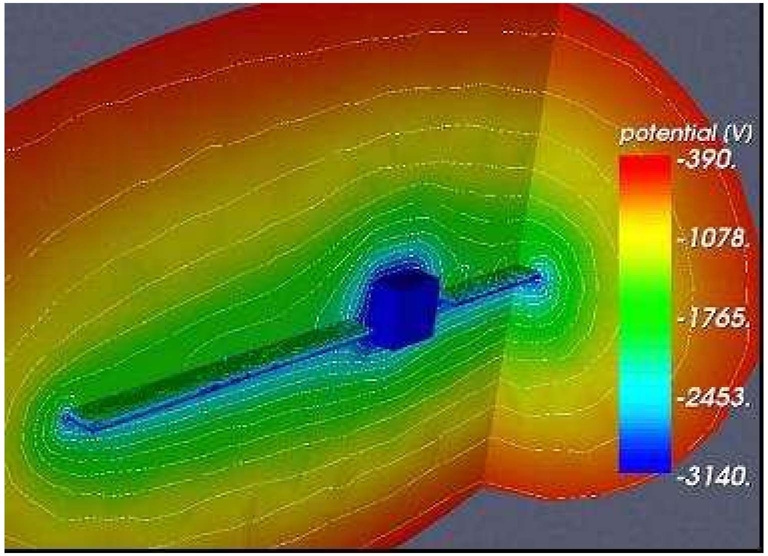
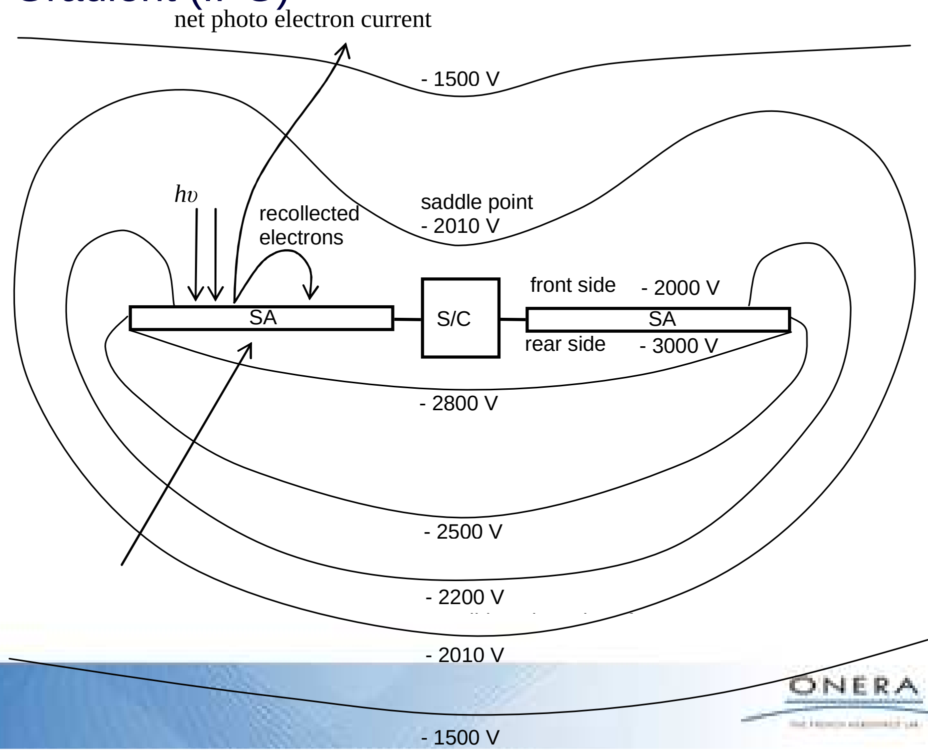
Charging at GEO

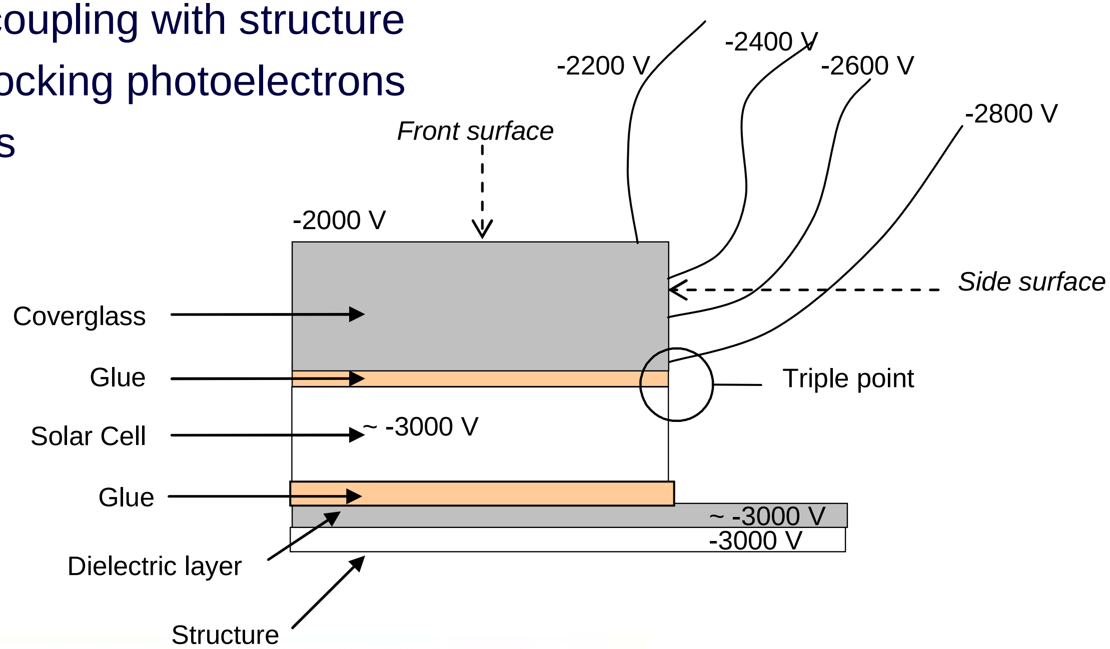
- Example of Spacecraft Charging at GEO in sunlight
  - S/C structure at -3000 V (on the example below) due to electron collection
  - Effect of the barrier of potential (-2010 V) on the front side due to rear side negative potential
  - Dielectric solar cell cover glass at -2000 V due to photo emission and barrier of potential
  - This situation is the Inverted Potential Gradient (IPG)





Charging at GEO

- Example of Spacecraft Charging at Solar Cell level
  - Gap surface covered with (photoconductive) kapton
  - Solar cell voltage is close to the structure voltage (strings voltage ~100 V)
  - Cover Glass top surface is less negative than solar cell (global differential charging)
  - Gradient of potential in between is influenced by
    - conductivity
    - capacitive and conductive coupling with structure
    - local barriers of potential blocking photoelectrons
  - It extends over a few millimeters
  - Triple point between conductor, dielectric and vacuum



Discharges

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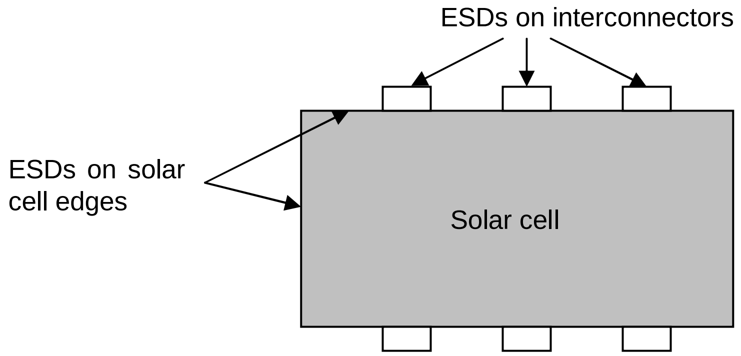
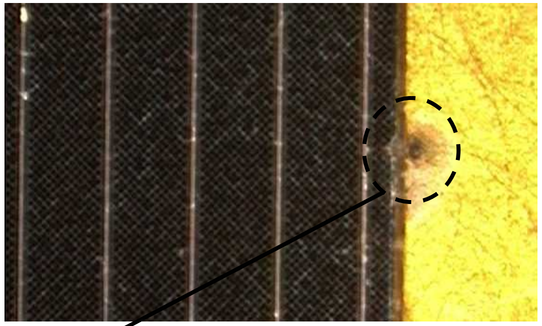
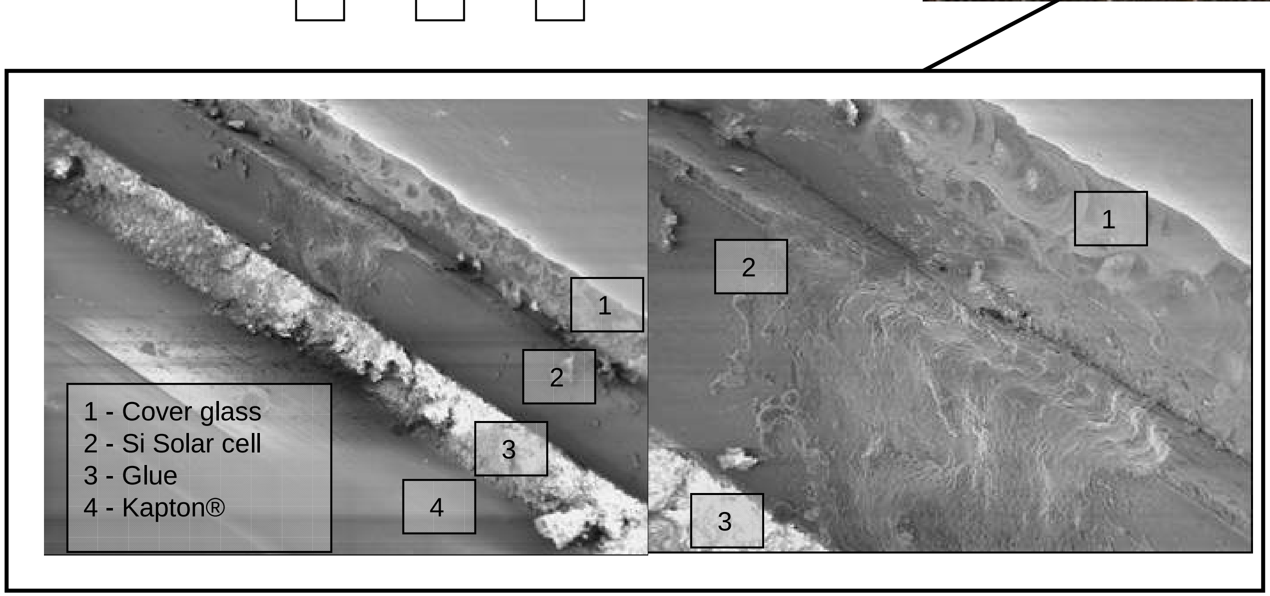
Discharge process

- ESDs occur at triple points – Example of solar cells



Laboratory experiments



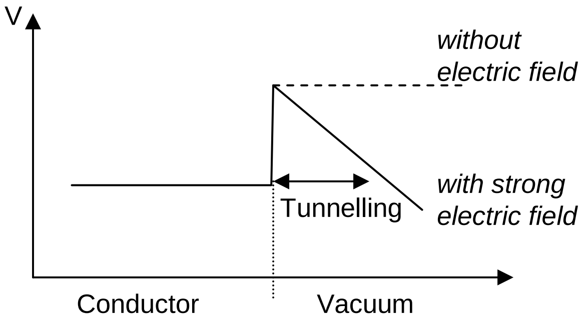


Discharge process

- Discharges on solar panels
  - Ignition can possibly be due to a wide range of events
    - micrometeoroid impacts
    - dielectric breakdown
    - man-made plasma production
    - local pressure increase (leading to a Paschen's discharge)
    - or field emission due to an electrical field enhancement (EFEE) in the vicinity of a triple point (conductor-dielectric-vacuum)
  - EFEE is thought to be the predominant mechanism for ESDs in IPG at solar panel Triple Points

Discharge process

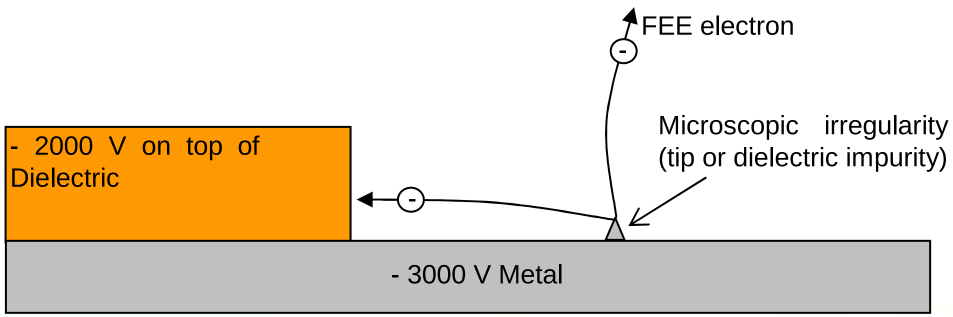
- Theory / Models
  - Breakdown mechanisms (leading to the initial blow-off current)
    - the important phenomena are electron emission mechanisms, induced by electric field or heat



Thermic effect $J_T = AT^2 \exp\left(-\phi_w / kT\right)$

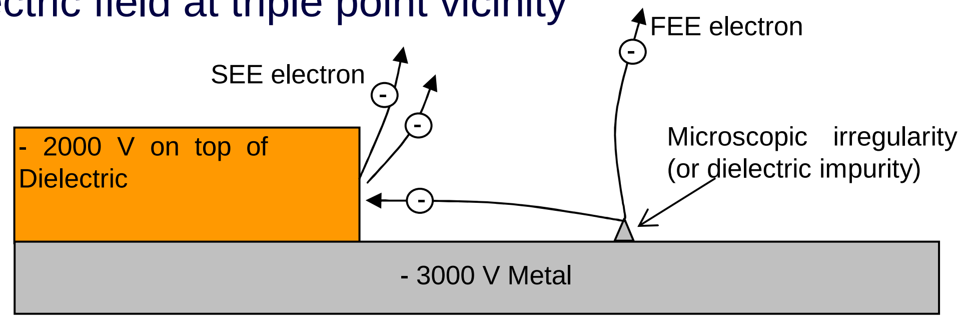
Field effect (tunneling) $J_{FN} \sim E^2 \exp\left(-B\phi_w^{3/2} / E\right)$

- at the beginning, field effect emission (FEE) is produced at micrometer scale by surface irregularities (tips, dielectric layers → field enhancement greater than 100)



Discharge process

- Theory / Models
  - Electrons colliding with dielectric surfaces can produce secondary emission (SEE) with a yield greater than 1 (depending on their energy)
  - It increases the electric field at triple point vicinity



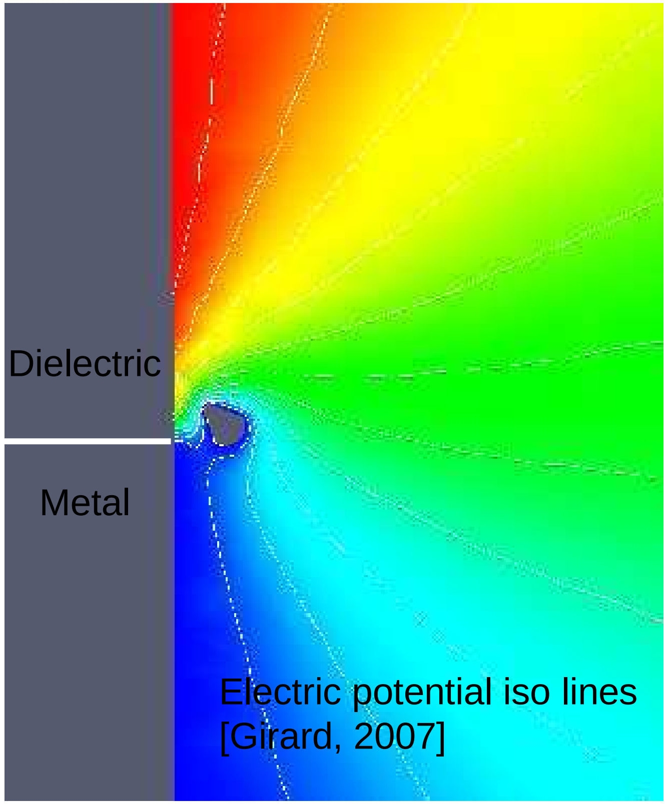
  - The loop is closed → divergent process → electron avalanche

Phenomena	**Effect**
Microscopic asperity	Increases electron avalanche risk
SEE with yield >1	Increases electron avalanche risk
Conductivity	Decreases electron avalanche risk
Electric field / Geometry	Field lines can prevent FEE electrons from colliding with dielectrics SEE electrons may be recollected due to barriers of potential

Discharge process

- This breakdown model has been simulated with SPIS, with a triple point modelled by a microscopic tip
  - Reference: "SPIS modelling of electrostatic discharge triggering in a solar cell gap, 10th SCTC, Girard et al., 2007
  - But simulation run at charging time scale → to be improved

- Next steps of the dicharge
  - Electron avalanche → cathode heating → thermofield effect → higher electron emission
  - Material fusion and vaporization
  - Metallic vapour → gas discharge → cathode spot (vacuum arc)
  - Blow-off current
  - Possible discharge of coverglass charge (flash-over)
  - Possible arcing between 2 solar cells strings



Specific Issues for ESD Hazard Modelling

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Specific issues for ESD Hazard Modelling

- The physics of electrostatic discharges on solar panels is multi-scale and multi-physics
  - Time scales of triple point charging : 10^3s
  - Time scale of electron avalanche and 10^{-9}s
  - Global charging at meter scale
  - Local triple point charging at mm scale
  - Microscopic irregularities
- ESD hazard assessment strategy must be developed with regard to the major parameters that influence the onset of ESDs
- Focus on initial electron avalanche by EFEE
- Criterion: if an electron avalanche occurs then ESD risk is assessed

Specific issues for ESD Hazard Modelling

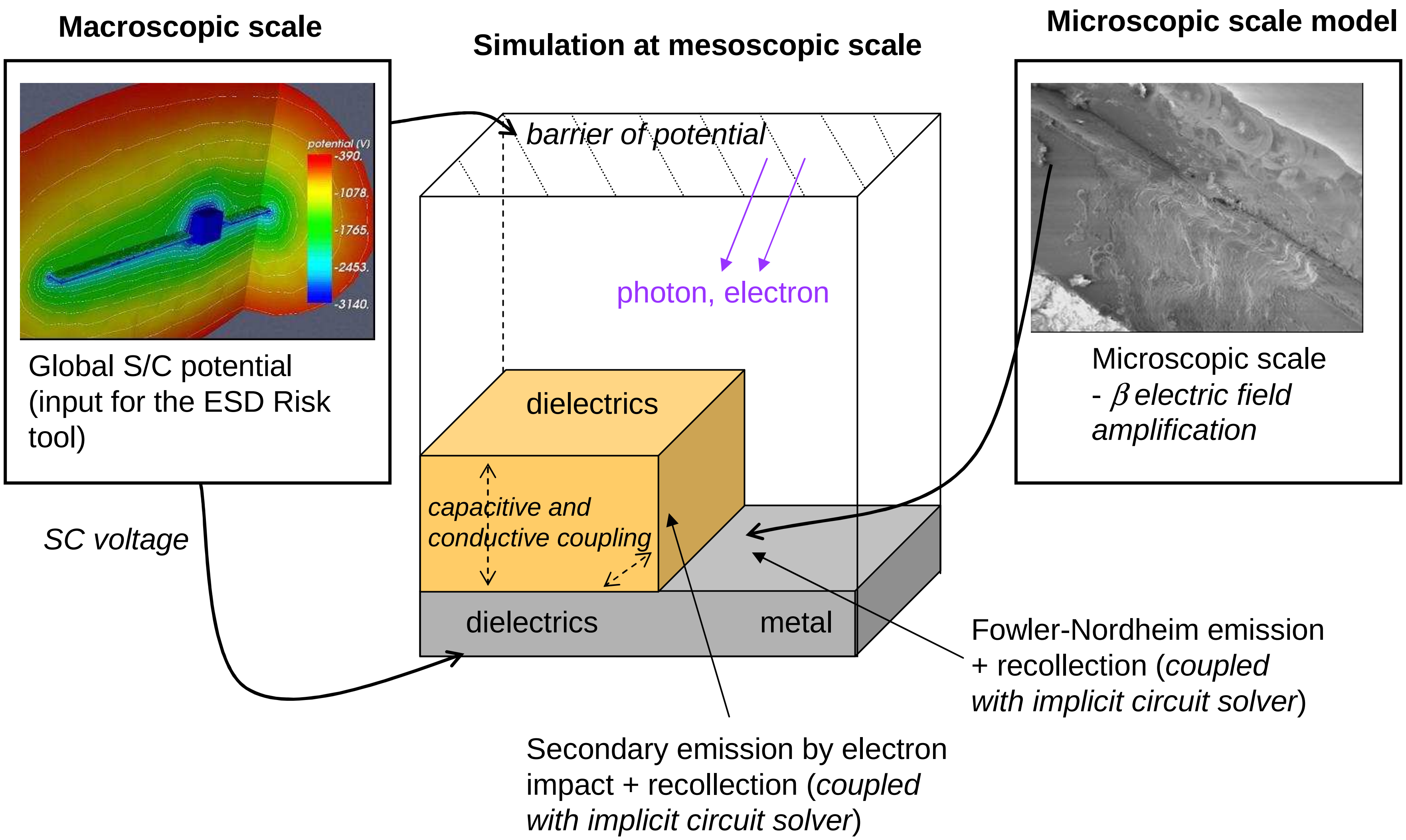
- Electron avalanche due to IPG at Triple Point depends on
  - Macroscopic spacecraft charging
  - Mesoscopic geometry of triple points
  - Microscopic structures

Necessity to take account of all these scales, but not to simulate all of them

- Simulation is foreseen at mesoscopic level on simple triple point geometry

- Various time scales must be handled

General view of the project



General view of the project

- User-friendly user interface

Conclusion

- The physical model aims at helping design engineers to estimate the ESD risk at triple points in IPG
- Very ambitious project
- Focus on the characteristic length scale of the differential charging and on the very beginning of the discharge
- Numerical developments in progress
- Experimental validation will be performed in ONERA vacuum chamber
  - threshold for ESD on various samples with different materials and geometries (perpendicular and co-planar triple points)