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# ONERA

THE FRENCH AEROSPACE LAB

[www.onera.fr](http://www.onera.fr)

# ESD risks and effects on spacecraft solar panels : Numerical tools and simulations

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Belhaj M., Murat G., Jarrige J.

# ESDs on solar panels

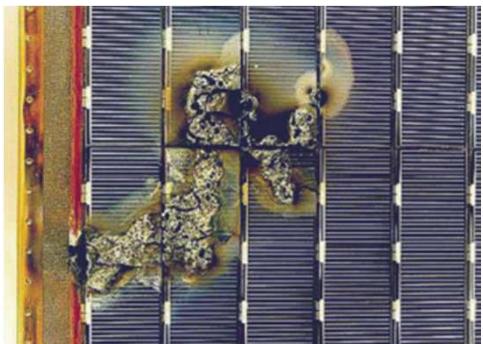
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Spacecraft solar generators are subject to differential charging by nature:

- several components
- several materials
- voltage and power generation

This differential charging may reach values such as an electrostatic discharge occur

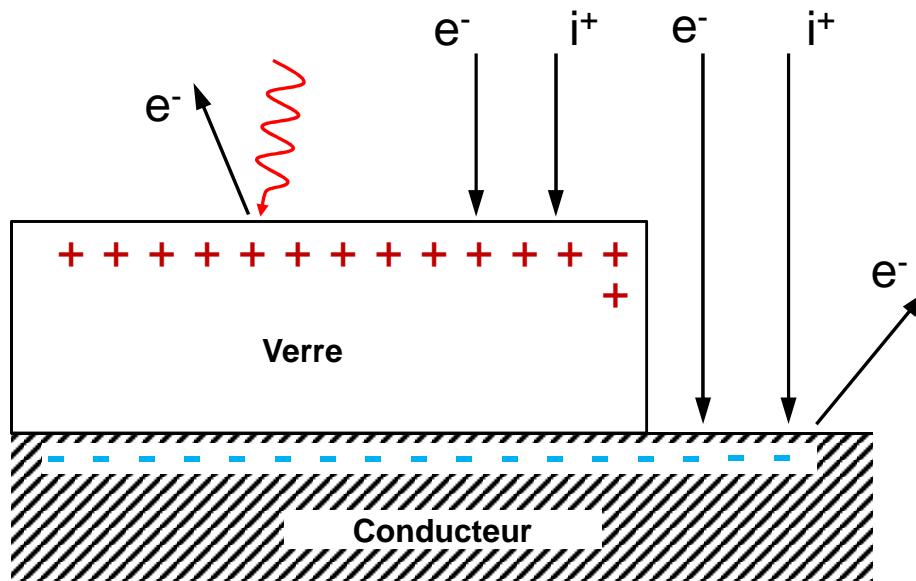


Questions:

- what is the exact ESD threshold?
- what are the parameters controlling it?

# ESDs on solar panels

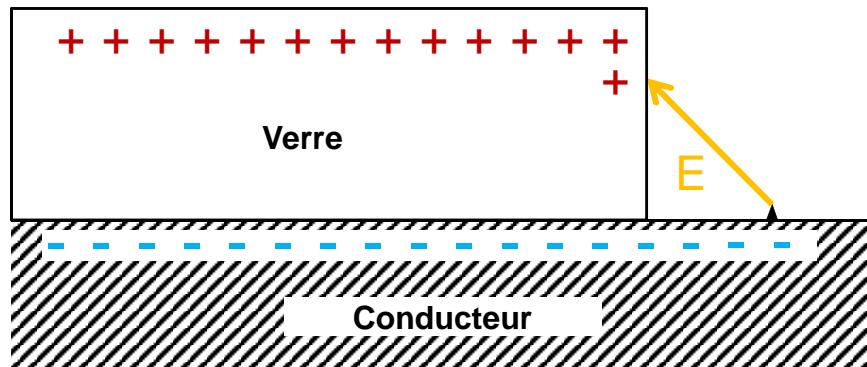
Surface charging by particle collection



# ESDs on solar panels

Surface charging by particle collection

Electric field builds up

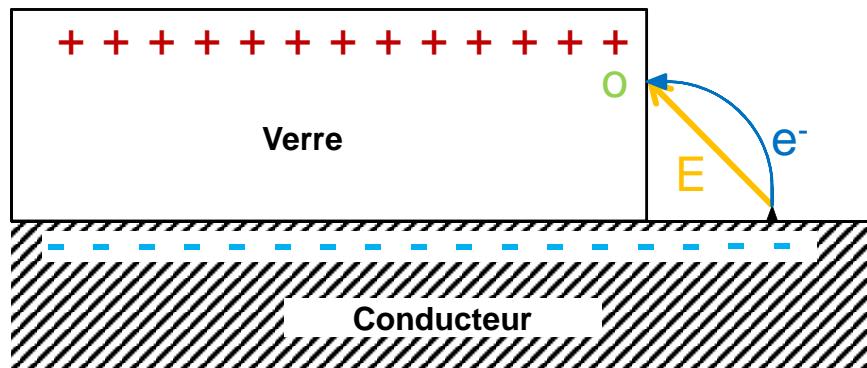


# ESDs on solar panels

Surface charging by particle collection

Electric field builds up

Electron emission & recollection



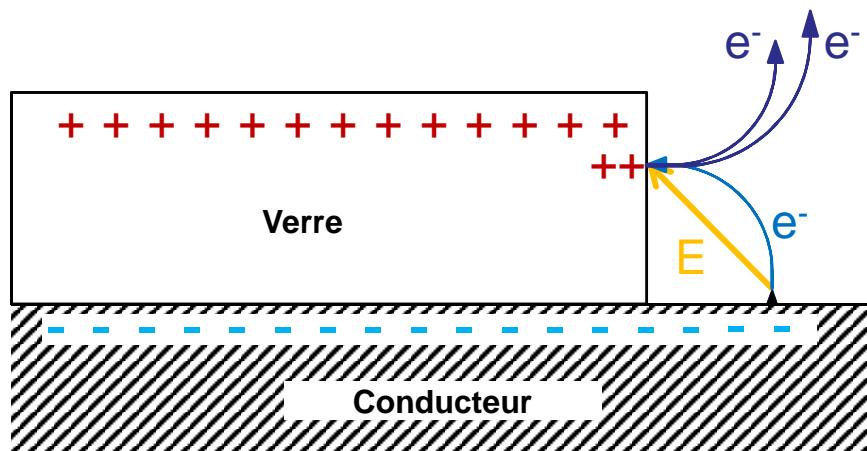
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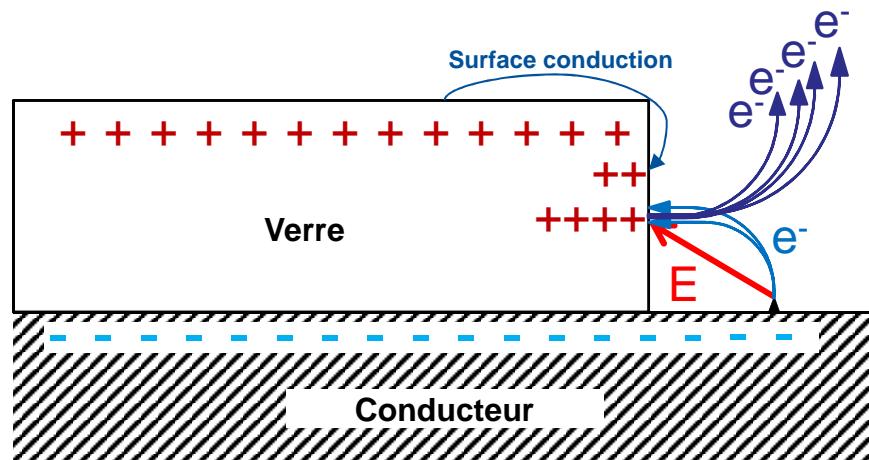
Electric field builds up

Electron emission & recollection

Secondary electron emission  
Charge increases



# ESDs on solar panels



Surface charging by particle collection

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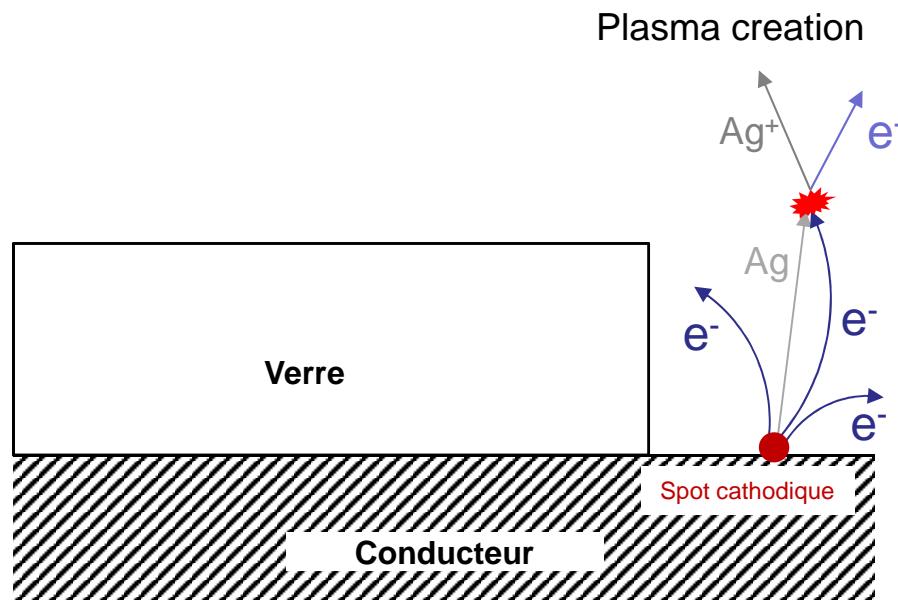
Electron emission & recollection

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Charge increases

Electric field increases

Cascade: current increases

# ESDs on solar panels



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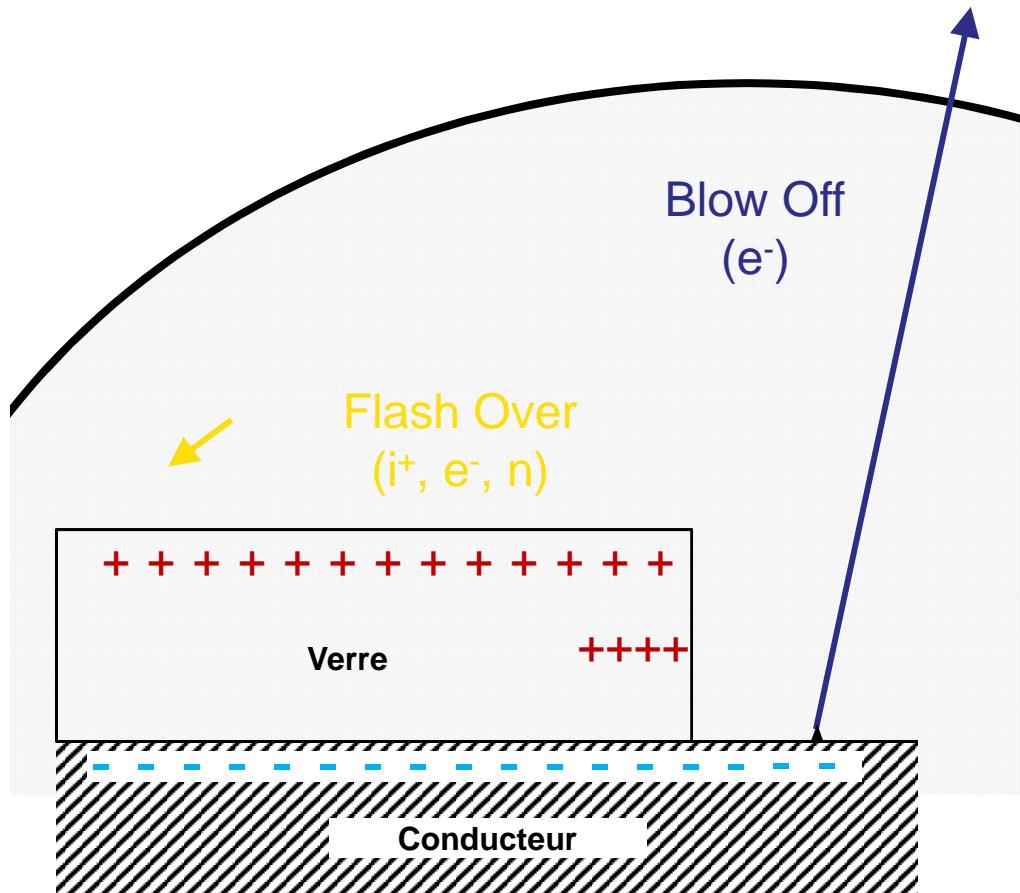
Electric field increases

Cascade: current increases

Temperature increases

Cathod spot + plasma creation

# ESDs on solar panels



Surface charging by particle collection

Electric field builds up

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Charge increases

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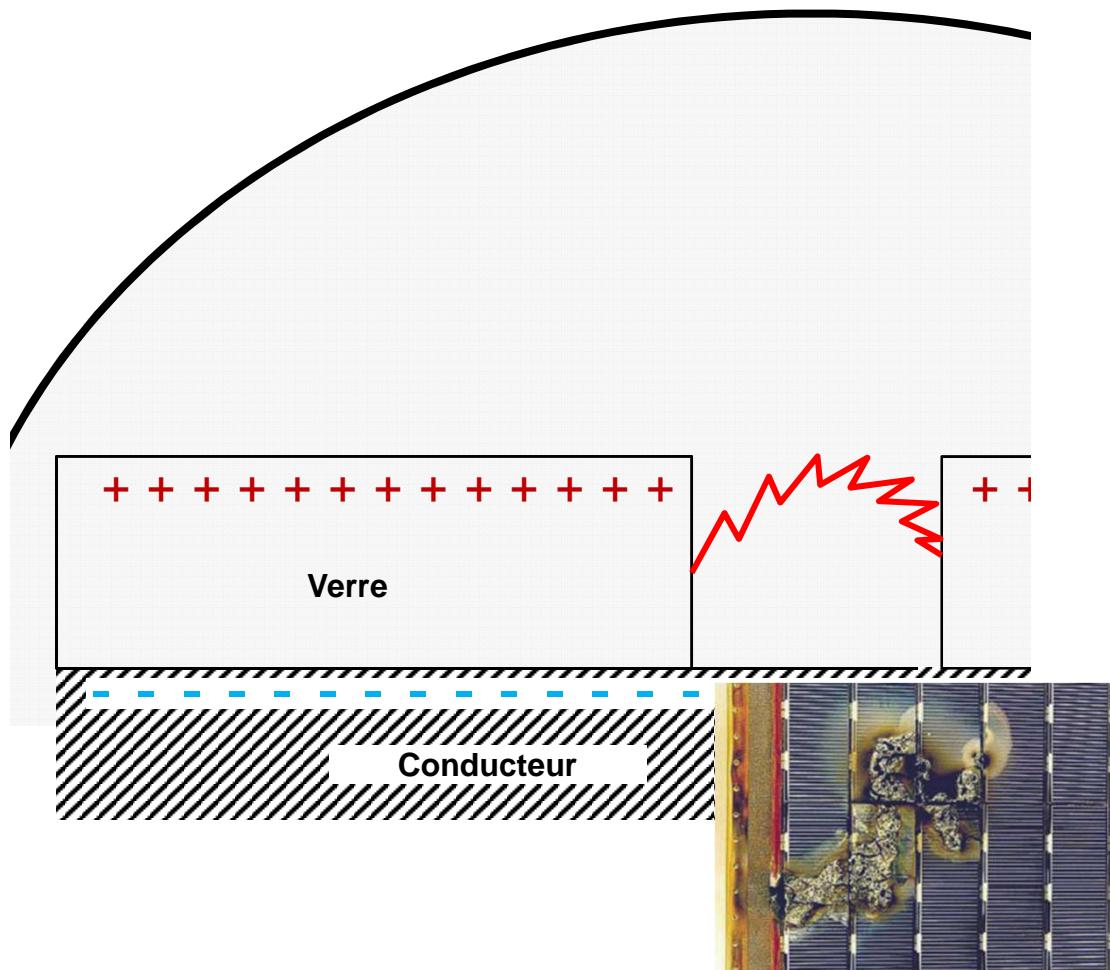
Cascade: current increases

Temperature increases

Cathod spot + plasma creation

Conductor discharge (Blow-Off)  
Dielectric neutralized (Flash-Over)

# ESDs on solar panels



Surface charging by particle collection ↑

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Charge increases

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Conductor discharge (Blow-Off)  
Dielectric neutralized (Flash-Over)

Conducting path: secondary arc

This talk ↑

Next talk ↓

# SPIS-ESD and further developments

Slow charging (minutes) by current balance

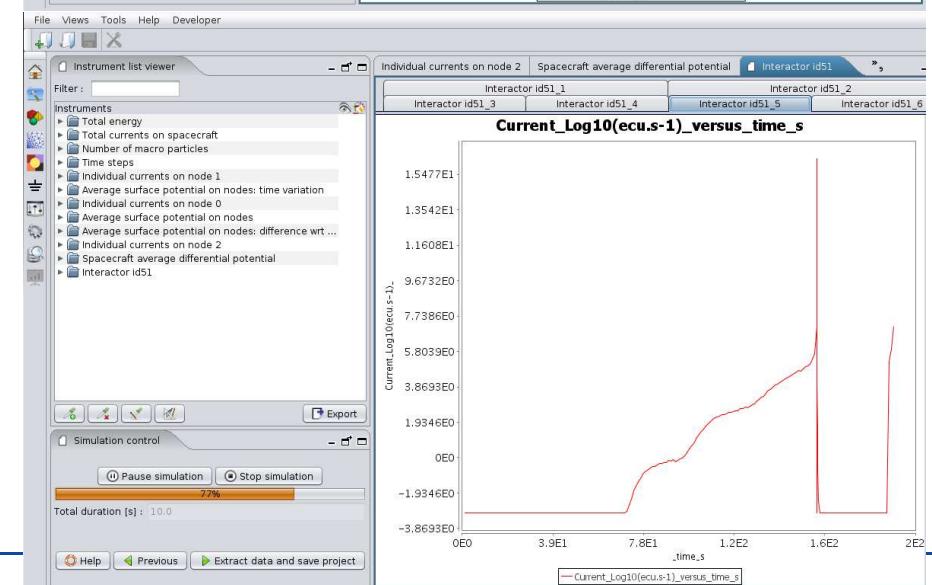
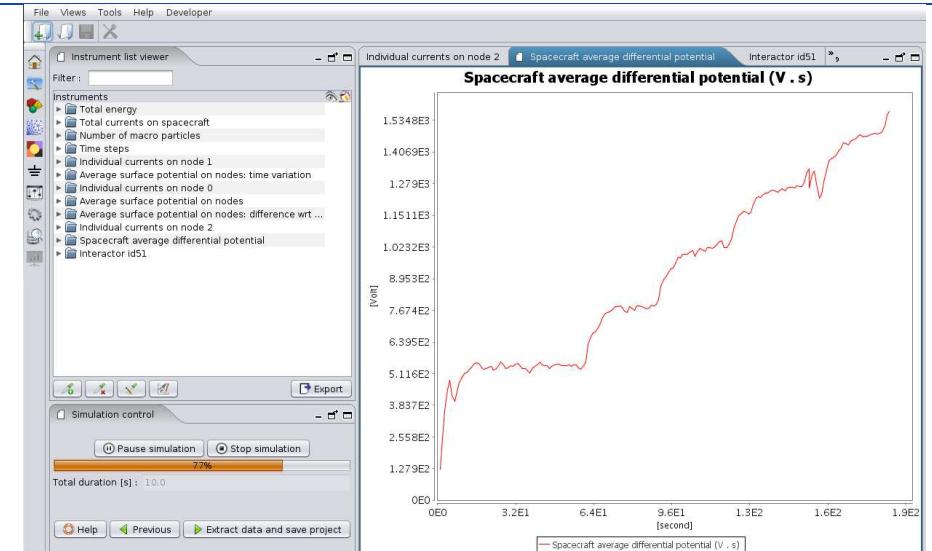
Rapid discharge (down to nanosecond)

Circuit solver includes a current predictor to handle the time step variation over 10 decades

Predictor is non-local (depends on the difference between the tip and the cover glass)

Correct charging dynamics requires exact capacitance calculation for each element

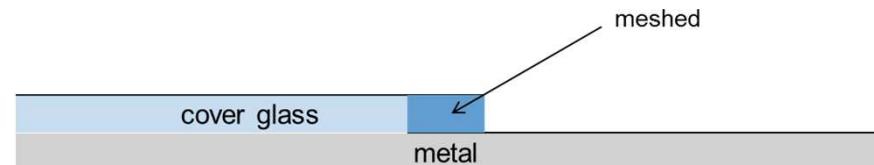
Analytical solution for some geometry only



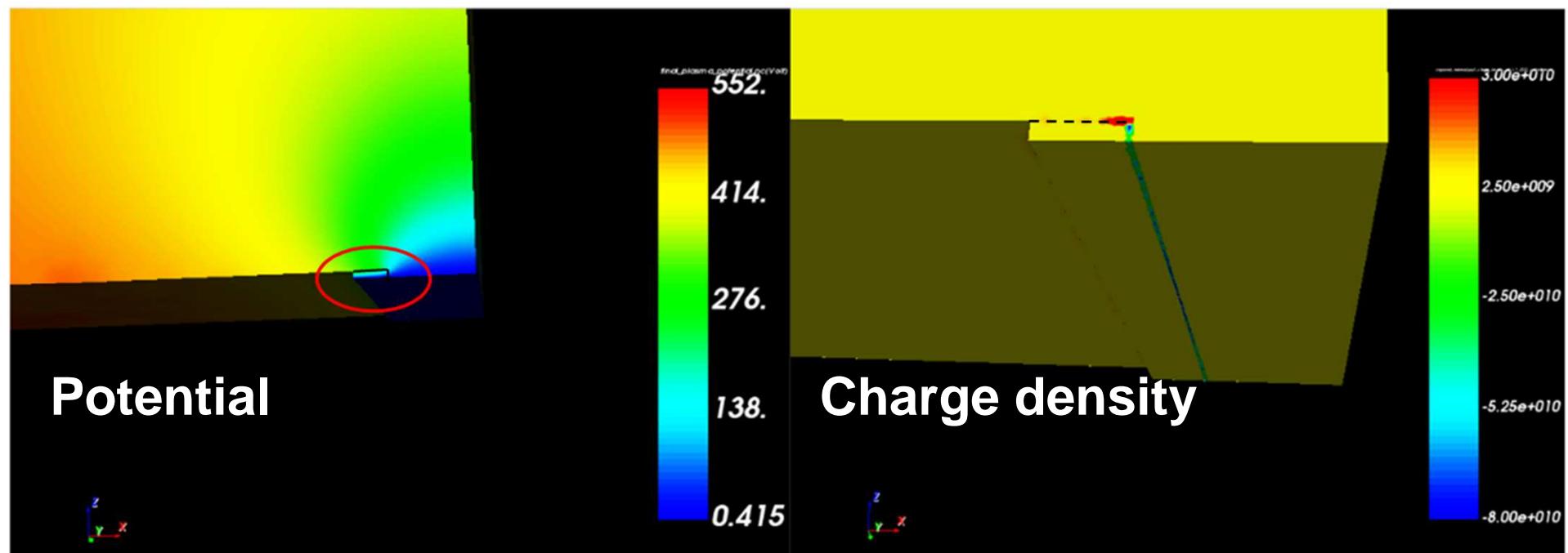
# SPIS-ESD and further developments

Correct charging dynamics requires exact capacitance calculation for each element

Analytical solution for some geometry only!



Need to mesh in volume and solve the charging through Poisson computation.  
Implemented in experimental SPIS plugin.



# Voltage Threshold: dependance on parameters

- When does ESDs occur: what is the voltage threshold?
- ESDs are the result of the growth of the electrostatic charge due to the combination of :
  - The electric field induced electron emission (**Fowler-Norheim**)
    - Increase with dielectric potential  $U$
    - Decreases with distance (~dielectric thickness)  $\lambda$
    - Decreases with metal **work function**  $\phi_W$
  - The current balance on dielectric
    - Increases with **secondary emission** on the dielectric  $Y_{eff}$
    - Decreases with the **surface conduction**  $\sigma_{\square}$

$$AY_{eff} \frac{\beta^2 U^2}{\phi_W \lambda^2} \exp\left(-\frac{B\lambda\phi_W^{3/2}}{\beta U}\right) > \frac{U\sigma_{\square}}{\lambda^2}$$

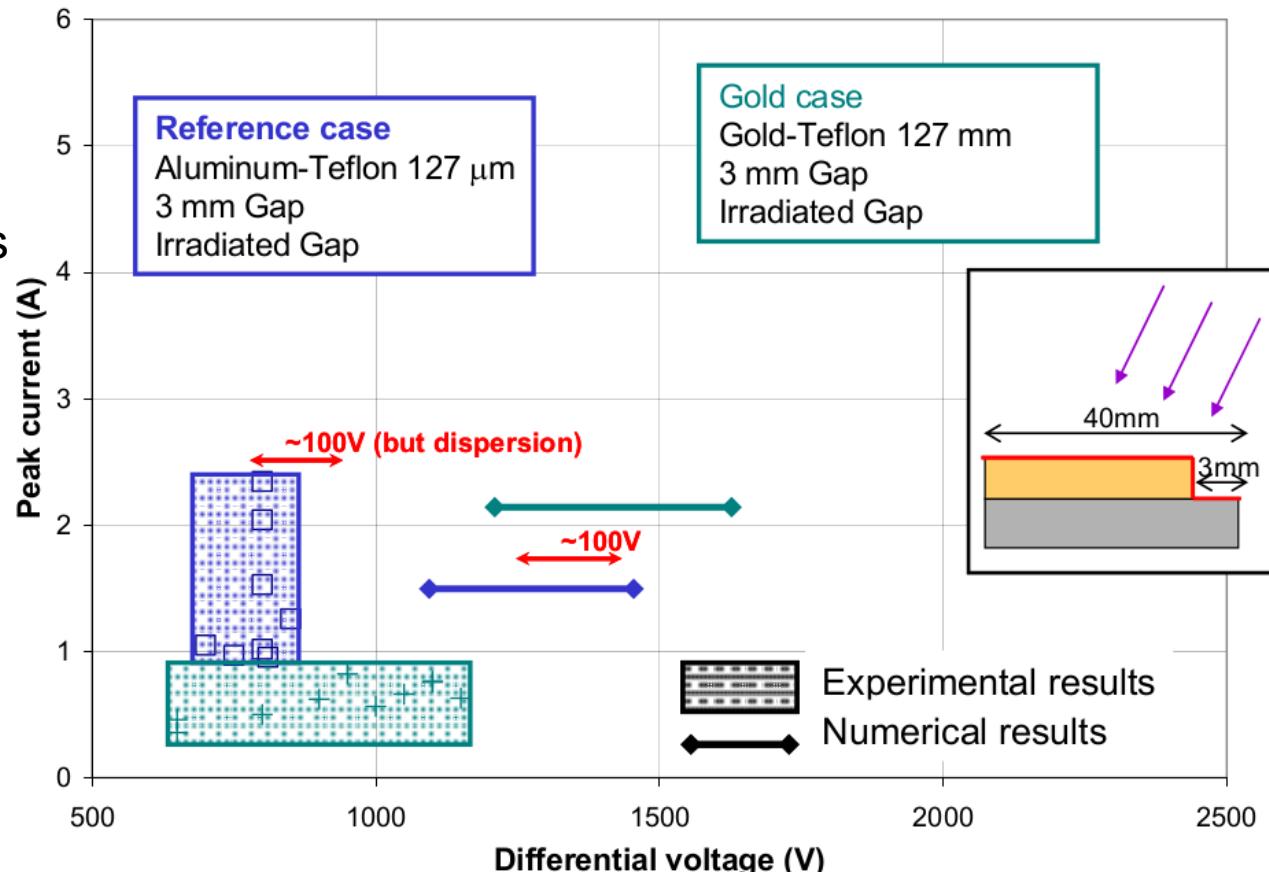
- Experimental testing & SPIS-ESD simulations

# Voltage Threshold: dependance on parameters (SPIS-ESD - 2010)

Experimental + numerical test campaign

Tested material parameters  
metal work function  
dielectric conductivity

Tested geometry impact  
gap size  
dielectric edge  
lighting



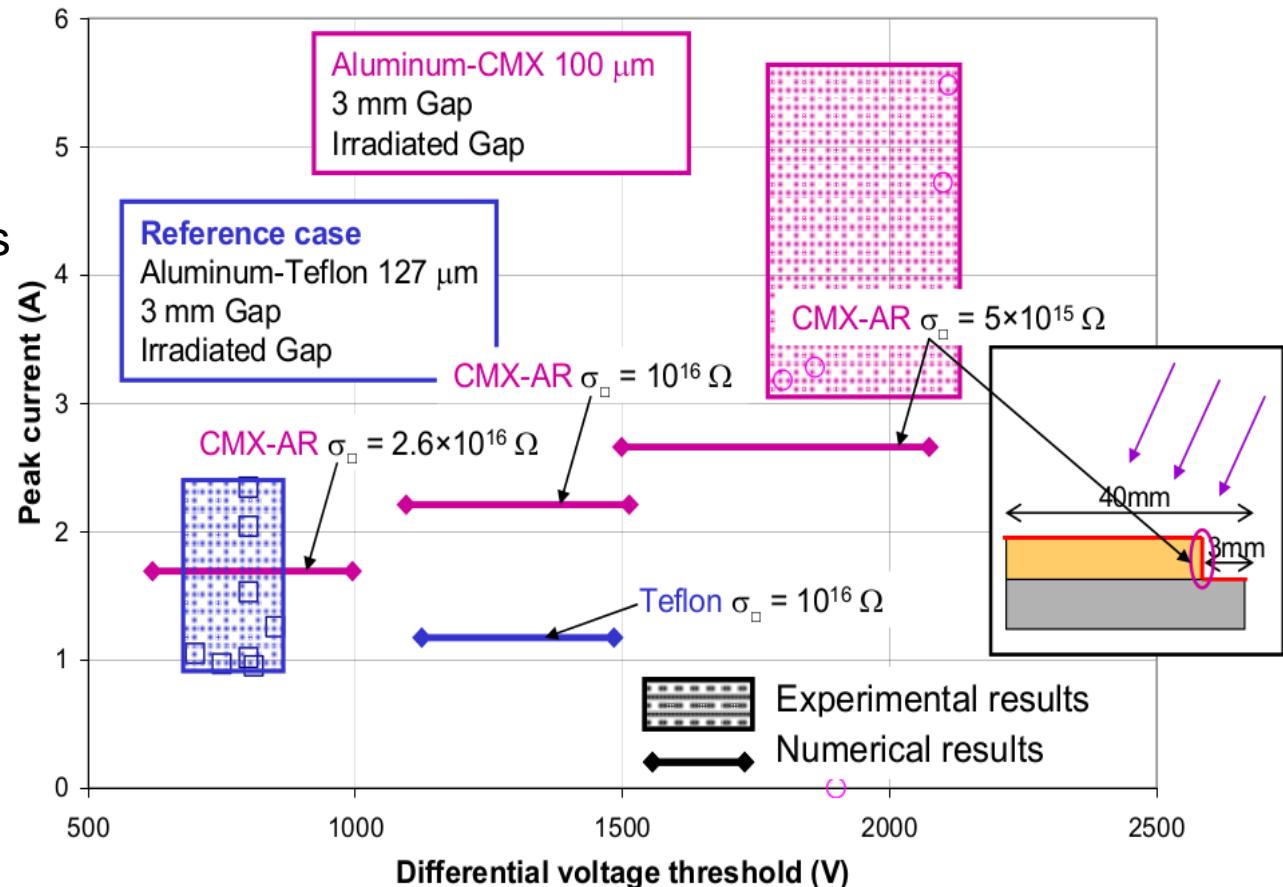
Work function effect:  
Need more potential to extract electrons from material

# Voltage Threshold: dependance on parameters (SPIS-ESD - 2010)

Experimental + numerical test campaign

Tested material parameters  
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Surface conductivity effect:

Need more potential to increase the Fowler-Nordheim current and counter balance the conductivity.

# Voltage Threshold: dependance on secondary emission?

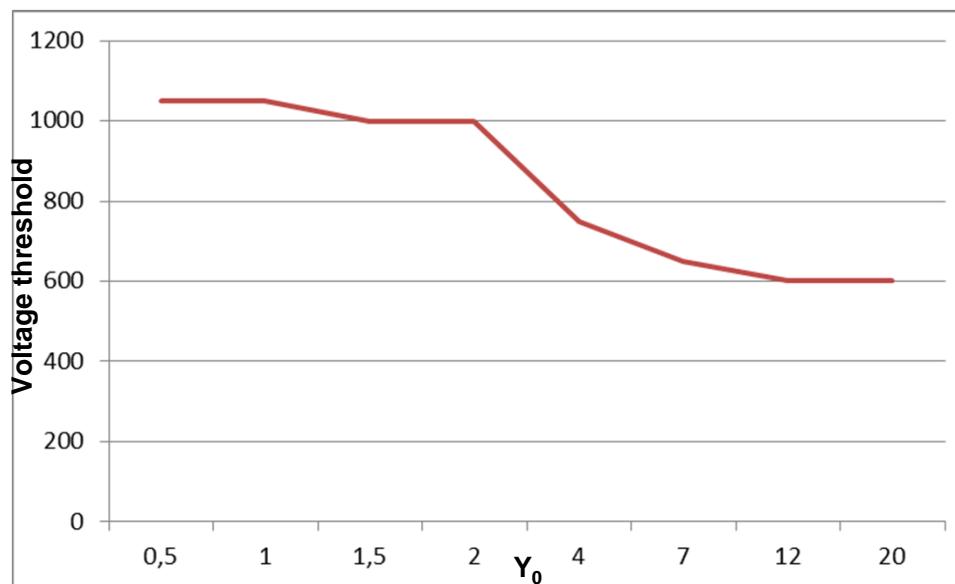
- How do the ESD threshold depend on secondary emission?
  - Not tested in the SPIS-ESD activity
- CNES-ONERA study: tested the impact of contamination and ageing on ESD threshold (experimental + numerical)
  - Secondary emission properties and surface conductivity measured for samples
  - Too much variability in the sample batch to analyse experimental data
  - SPIS results:

Sample	$E_{\max}$ (eV)	$Y_0$	Surface Resistivity ( $\Omega \cdot m$ )	Events
Pristine	200	2.4	$5 \cdot 10^{15}$	Fusion : 1000V ESD : 1166V (x2), 1500V (x3)
Eroded 1h30	280	1.95	$5 \cdot 10^{14}$	Fusion : 2466V ESD : 2866V
Eroded 3h	350	1.8	$5 \cdot 10^{14}$	ESD : 2300V, 3500V
Contaminated	350	2.4	$2 \cdot 10^{14}$	Fusion : 3100V ESD : 3100V

- Clear surface conductivity effect. What about secondary emission?

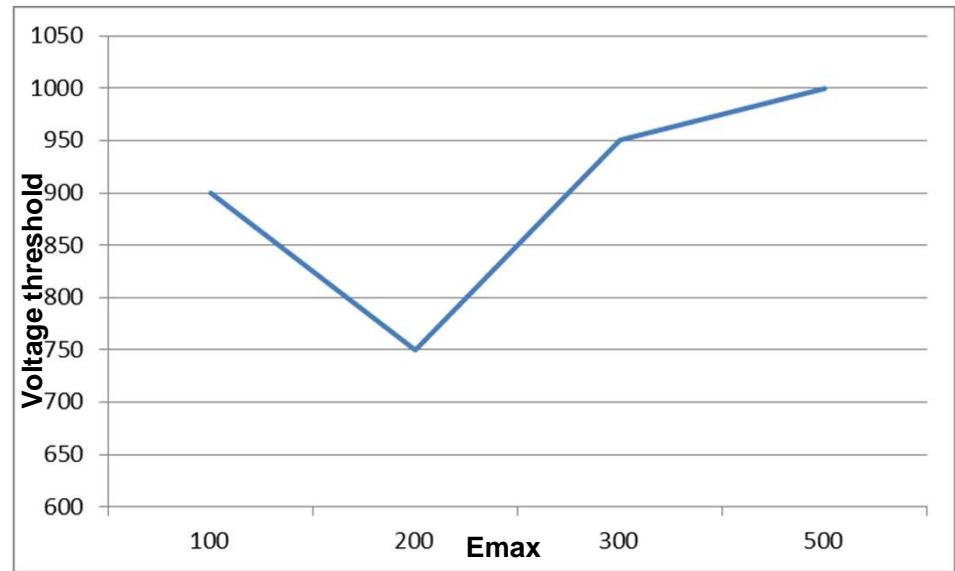
# Voltage Threshold: dependance on secondary emission!

- New CNES – ONERA activity
- Parametric study ~50 SPIS-ESD simulations to test impact ad coupling of surface conductivity and secondary emission parameters.
- No strong SEEE/conductivity coupling: can be decoupled in the models
- Voltage threshold decreases with increasing yield (makes sense!)



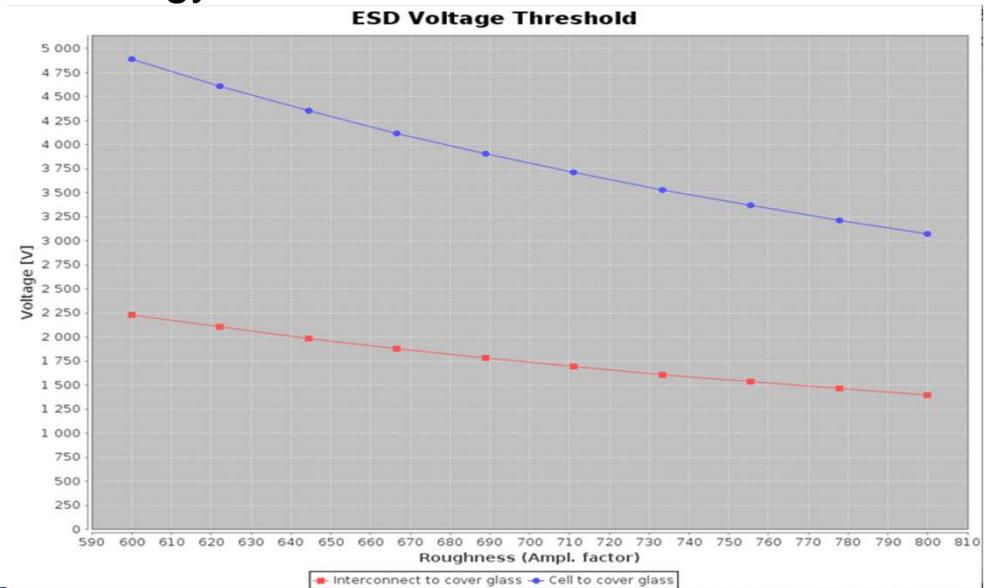
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- Non-linear dependance on peak incident energy!
  - Minimum threshold near 200eV
  - Physics to be investigated



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- Voltage threshold decreases with increasing yield (makes sense!)
- Non-linear dependance on peak incident energy!
  - Minimum threshold near 200eV
  - Physics to be investigated
- Implemented in an empirical model.

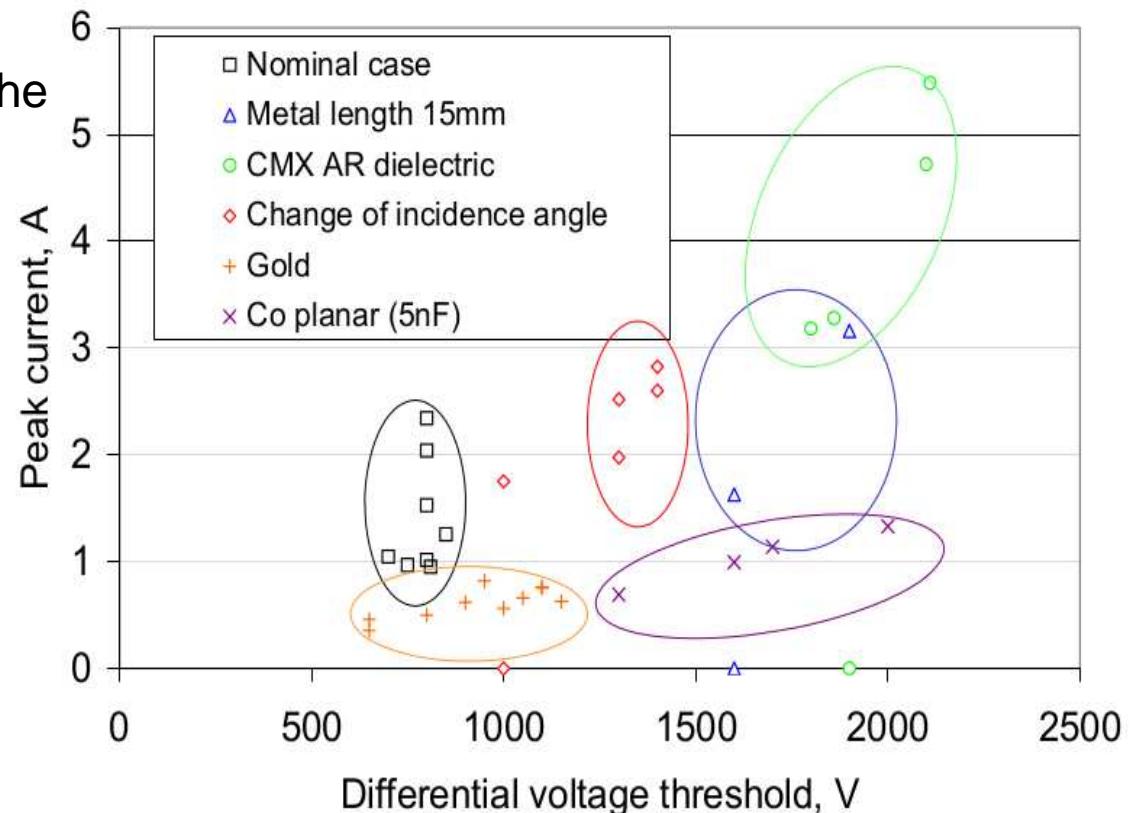


# Voltage Threshold: Effect of geometry...

The initial SPIS-ESD study showed effect of the geometry (ligh angle, dielectric shape, gap size...)

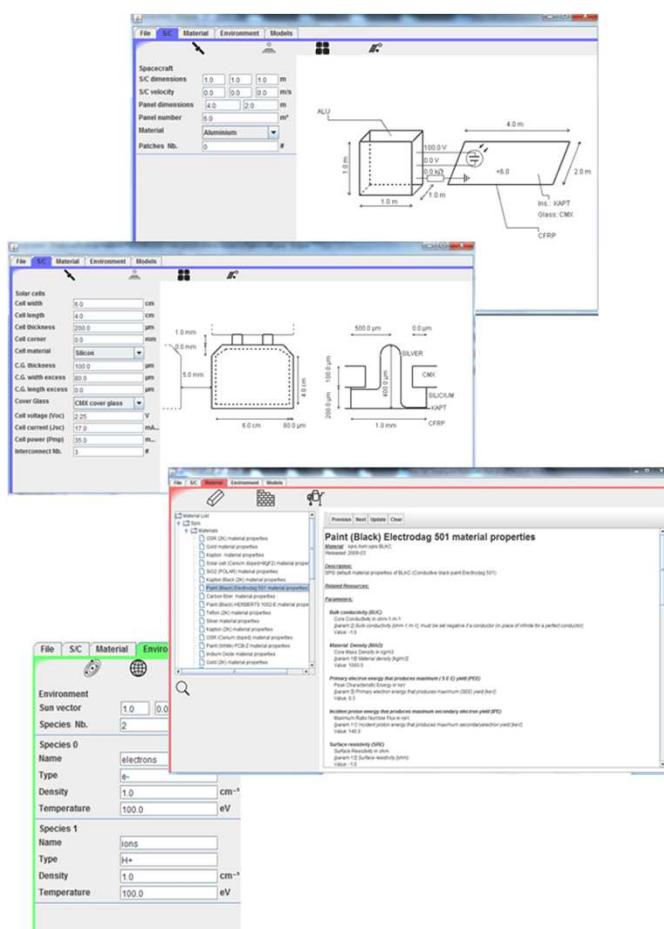
To be investigated in detail using the SPIS-ESD / SPIS-IC coupling

Result for the SPINE 2022...



# SoCCER tool: Solar Cells Charging and Electrostatic Risks

Empirical threshold model embedded in an ONERA software dedicated to modelling of solar generators and cells



Engineering oriented:

Light-weight graphical interface

Limited number of parameters (simplified geometry)

Simple models to investigate one phenomenon at a time



Modular: models can be added as plugins

HiVES: Current collection by High-Voltage Elements

COMET: CNES-ONERA Model of ESD Threshold

FOEBUS: Flash-Over Bubble Simulator

ChaMISEn/SPASE module for material & environment databases

# ESDs effect: Blow-Off and Flash-Over

ESD prevention is only a part of risk mitigation on solar generators

The cathode spot and plasma generated by the ESD couple with the solar panel

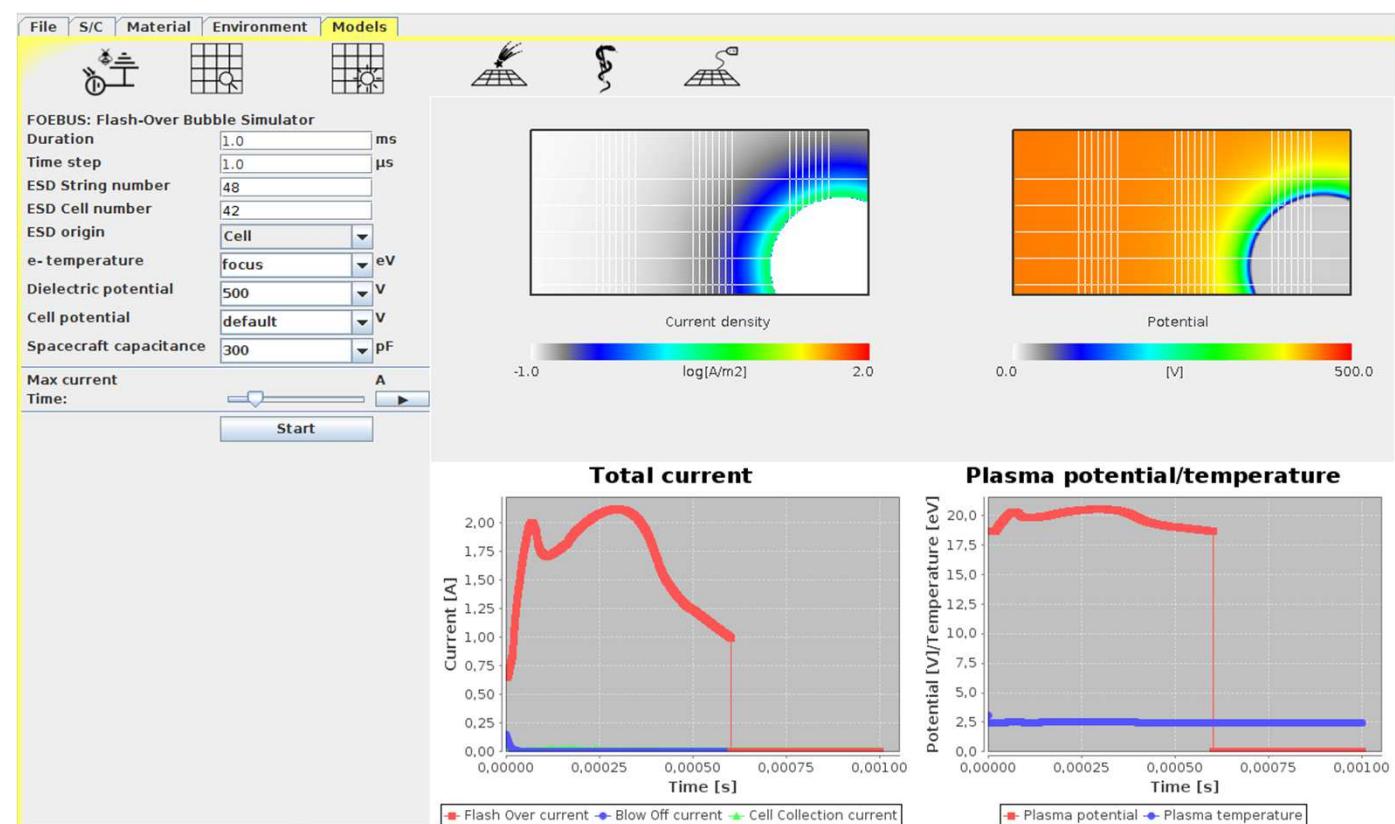
→ Blow-off

→ Flash-over

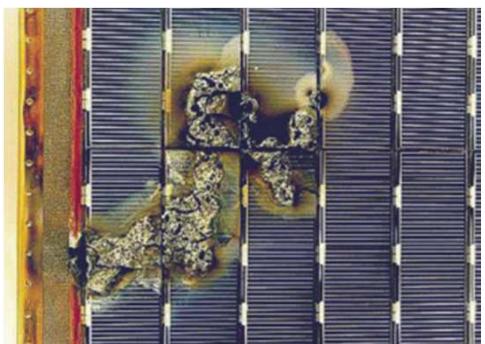
→ Arcs

Next talk!

Models in SoCCER.



# Conclusion



A semi-empirical model has been established

Impossible to set the model with experiments  
- too much variability  
- not enough control on parameters

Model parameters determined by a parameteric study with SPIS-ESD (>50 runs)

Effects of work function and surface conductivity as expected.

Effect of the secondary emission yield relatively straightforward

Non linear dependence on the peak energy.

Geometrical effects under investigation.