Material charging investigations for JUICE - 28th SPINE - online

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ESA ESTEC

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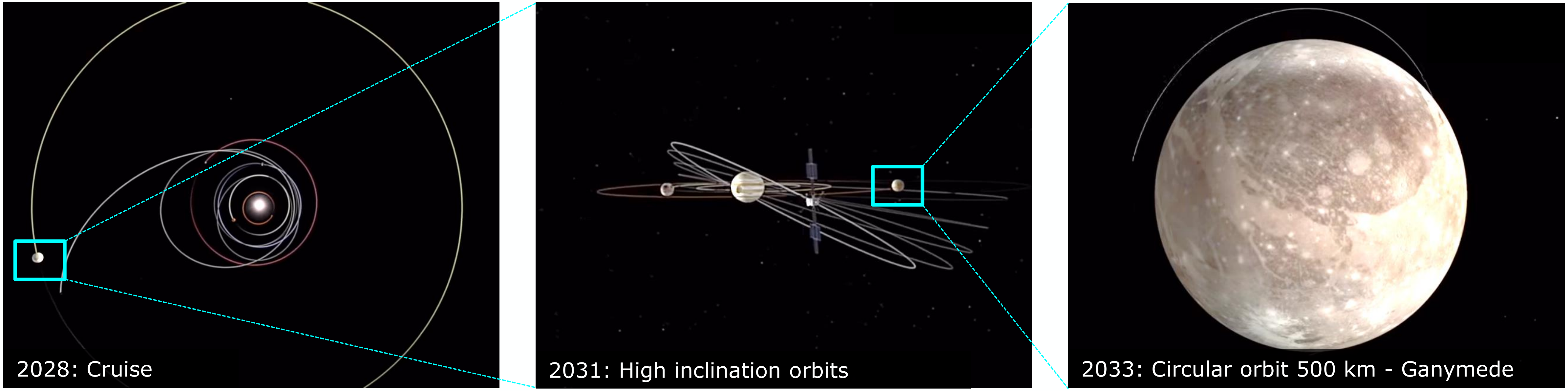
JUICE expected environment

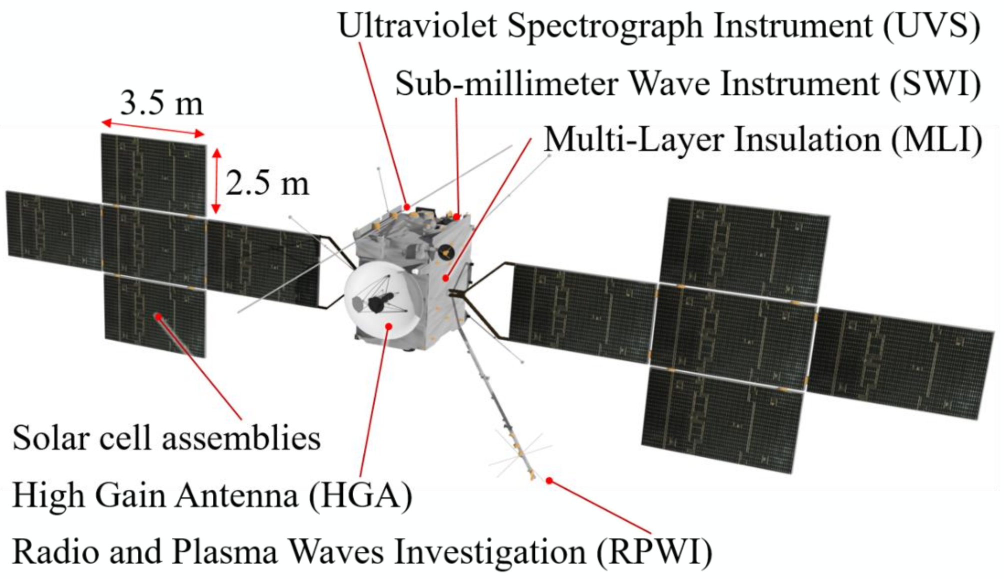


https://www.youtube.com/watch?v=KGkW__sEDHA

JUICE (Jupiter Icy Moons Explorer) is planned to launch in summer 2022 on a **7 years journey** using several **gravity-assists of Earth, Venus, and Mars** to reach the **Jupiter system**:

- Cruise in the inner solar system, the maximum expected solar flux is 3322 W·m^{-2}:
  - UV and thermal ageing
- Jovian system, the minimum expected solar flux is 46 W·m^{-2} and up to 4.8 h eclipses, intense radiation belt:
  - cryo-temperatures and low photoemission
  - electron and proton radiation ageing
- Ganymede orbit, ATOX fluence:
  - erosion and corrosion

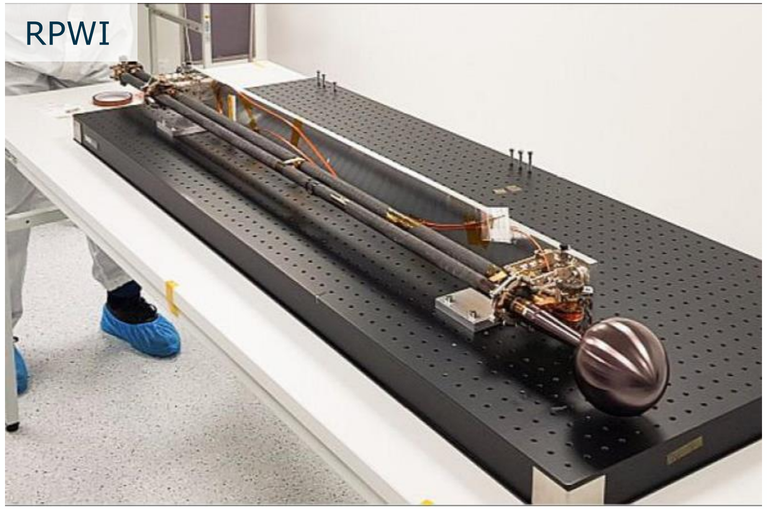
JUICE spacecraft presentation

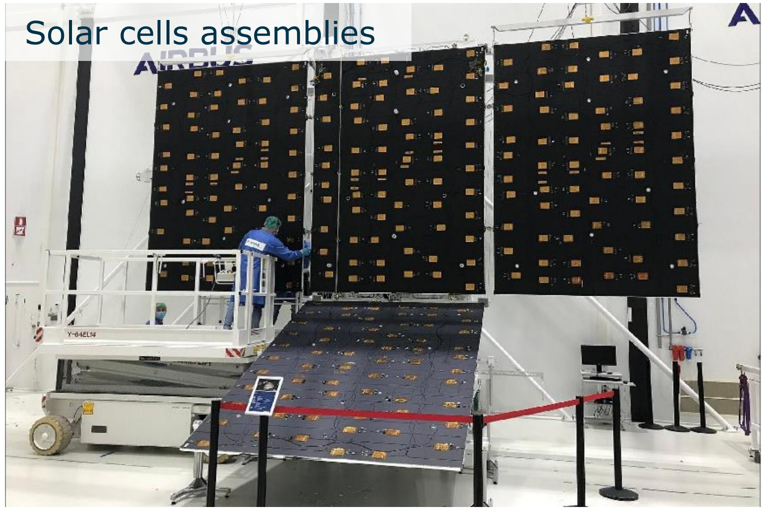


External surfaces of the spacecraft are expected to endure this diversity of harsh environments:

- Different materials
- Different location
- Different requirements
- **maximum gradient of few Volts** along the external surfaces of the spacecraft is **acceptable during science phase** (after materials ageing and at cryo-temperatures)


HGA


RPWI


Solar cells assemblies

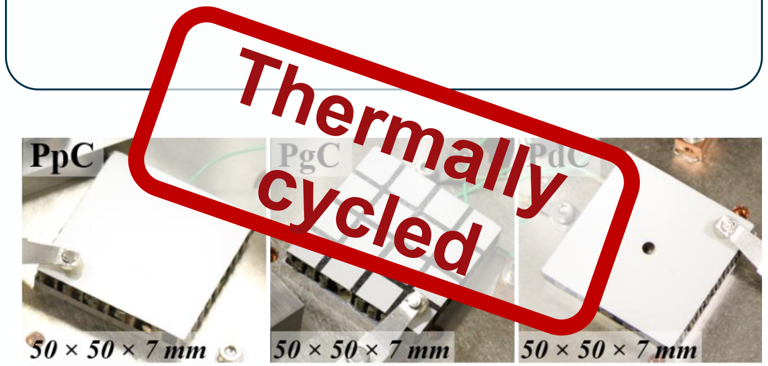
https://eoportal.org/web/eoportal/satellite-missions/content/-/article/juice

Overview of tested materials samples

White thermal control coatings:
proposed to fulfil the thermal control requirements of the HGA and several payloads' radiators and appendages like the SWI.

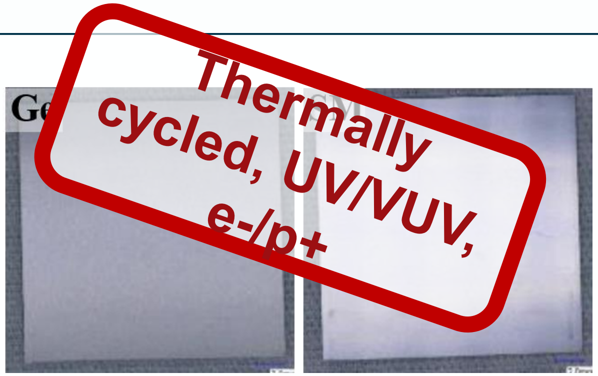
- PCBE
- Z-93C55
- AZ-2000-IECW

➢ More details in the next slide



MLI (multi-layer insulation):
2 proposed stacks used for the outmost layer.

- germanium coating topside /
1.6 mil (40 µm) 160 XC Black Kapton /
vapour deposited aluminium (VDA) coating backside
- StaMet (silicon aluminium alloy) coating topside /
1.6 mil (40 µm) 160 XC Black Kapton /
vapour deposited aluminium (VDA) coating backside



Solar panels rear side and **solar cells cover glass coating**:

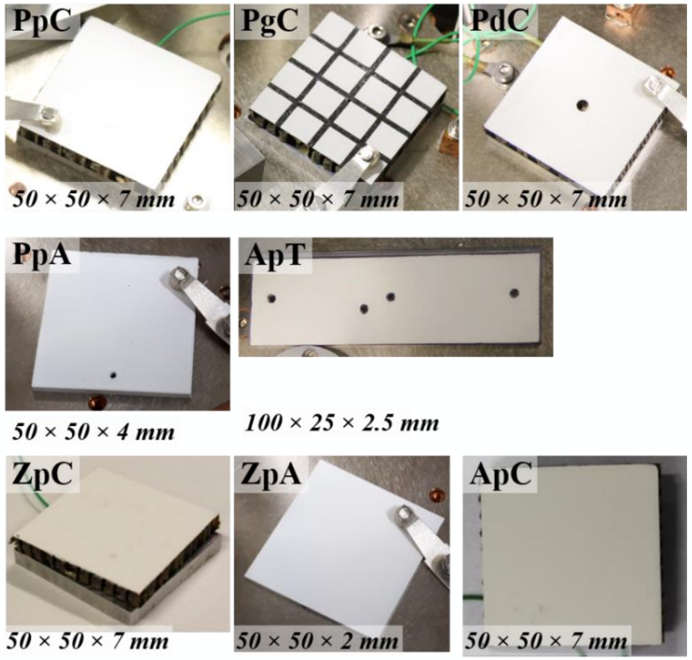
- 6-ply rigid array Mk4 CFRP skin co-cured with Black Kapton (DuPont Kapton 200RS100) with butt joint.
- ITO coated CMG cover glass

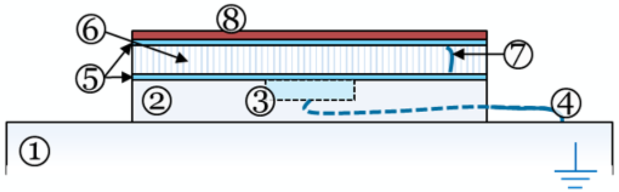
White thermal control coatings - samples

PCBE from MAP Space Coatings, Z-93C55 from Alion Science and Technology and AZ-2000-IECW from AZ Technology.

Prior electrostatic properties testing, **all samples were thermally cycled** under nitrogen ambient pressure for 20 cycles between -180°C and +180°C with a dwell time of 60 min at extremes.

ID	Paint / Expected thickness		Primer / Expected thickness	Substrate	Tested temperature (°C)
PpC-1	PCBE / 120 µm	plain	PSX / 1 µm	CFRP	RT / -150 / -210 / RT
PpC-2					
PgC-1		bare grid			
PgC-2					
PdC-1		bare disk			
PdC-2					
PpA-1		plain	Not specified	Al/Alodine	
PpA-2					
ZpC-1	Z-93C55 / not specified		MIX D-Z6040 / not specified	CFRP	
ZpC-2					
ZpA-1			Not specified	Al/Alodine	
ZpA-2					
ApC-1	AZ-2000-IECW / 75 µm to 126 µm		MLP-300-AZ / 13 µm to 25 µm	CFRP	
ApC-2					
ApT-1				Ta2.5W	RT / -45 / -170





① grounded baseplate
② sample adapter
③ aluminum grounding insert glued with conductive epoxy
④ grounding wire
⑤ grounded CFRP skins
⑥ Kevlar honeycomb
⑦ grounding strip
⑧ layer to be tested (paint, primer)

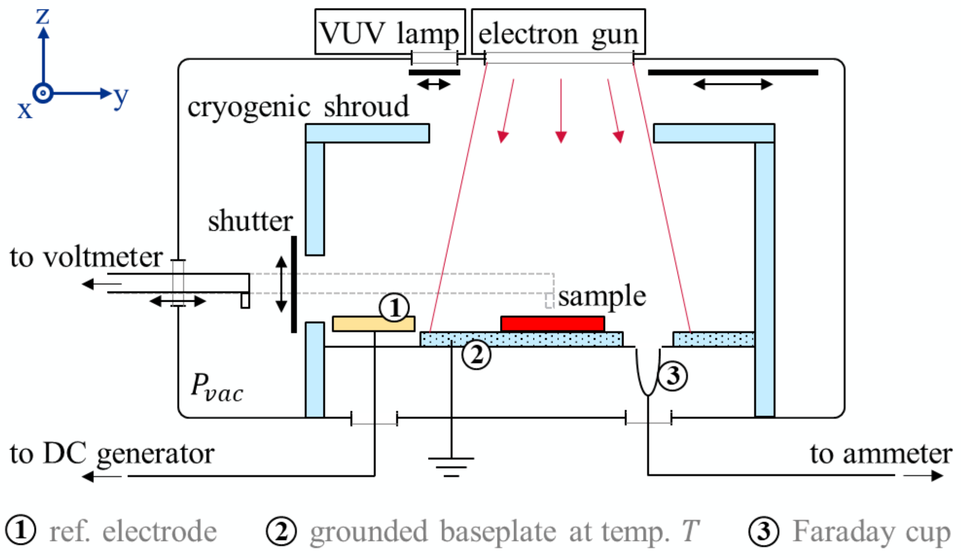
White thermal control coatings – ESD facility

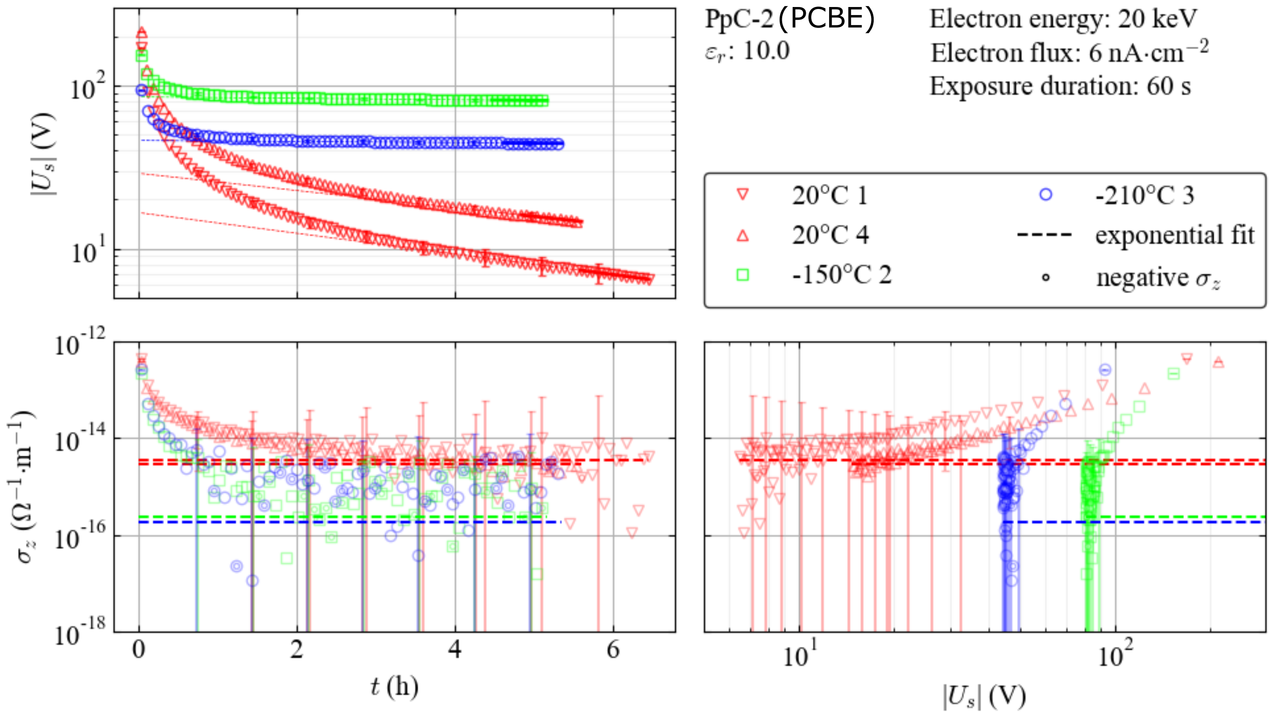
SPD (surface potential decay) method to extract intrinsic dark bulk electric conductivity of the layer σ_z, in $\Omega^{-1}\cdot m^{-1}$.

$$\sigma_Z(U_S(t)) = \frac{-\varepsilon_0 \varepsilon_r}{U_S(t)} \frac{dU_S(t)}{dt}$$

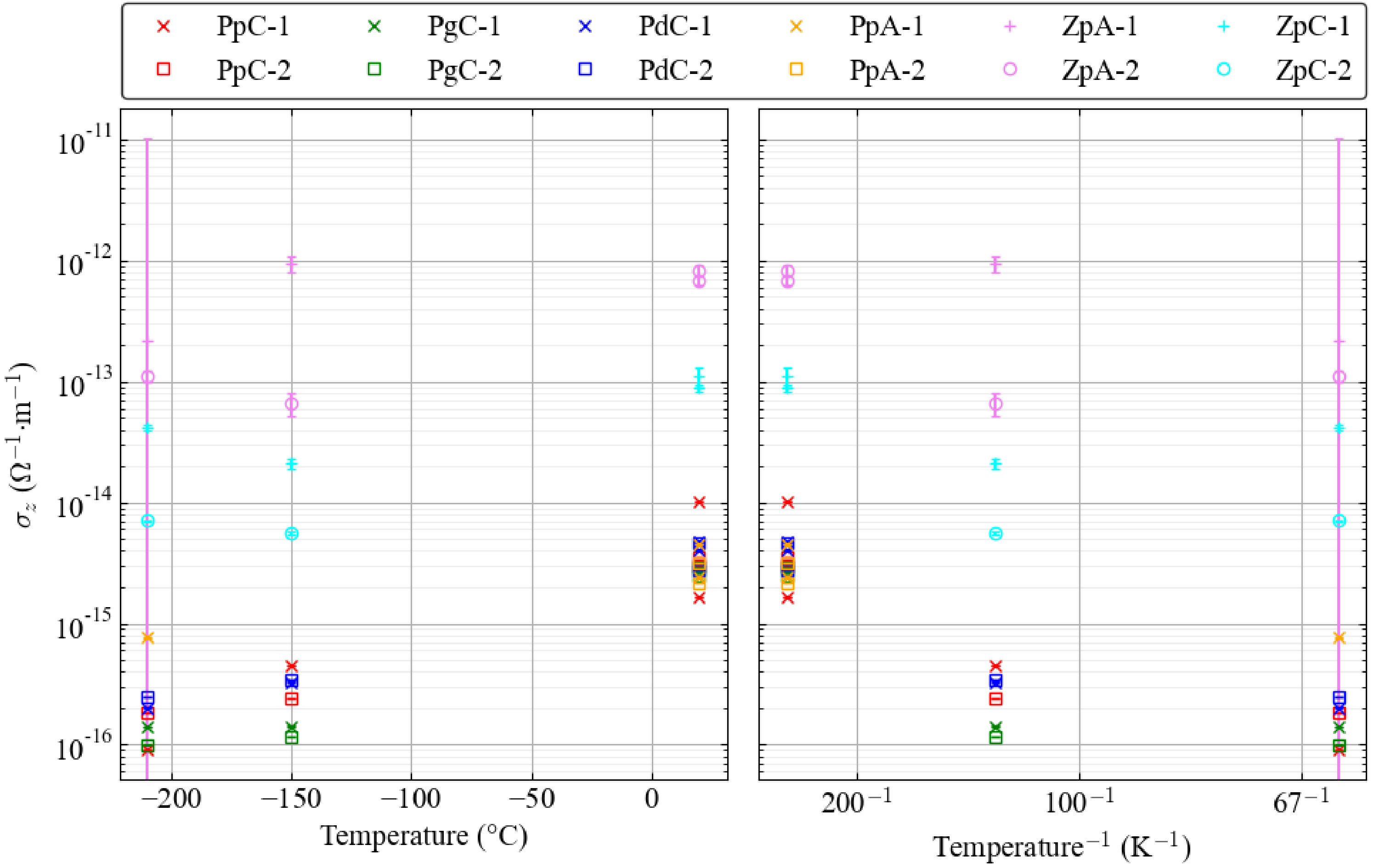
A relative permittivity of ε_r = 10 is assumed for all the paint.

Exposure with 20 keV electrons with a 6 $nA\cdot cm^{-2}$ flux density for 1 minute.





White thermal control coatings - results



PCBE:
- between ~5 × 10^{-15} $\Omega^{-1}\cdot m^{-1}$ at RT and ~1 × 10^{-16} $\Omega^{-1}\cdot m^{-1}$ at -210°C
- No significant $\sigma_z(T)$ variation is observed between the PCBE variants.

Z-93C55:
- challenged measurement limit because charging was barely observable.
- higher than ~5 × 10^{-14} $\Omega^{-1}\cdot m^{-1}$ on aluminium substrate at every tested temperatures.
- higher than ~5 × 10^{-15} $\Omega^{-1}\cdot m^{-1}$ on CFRP skin at every tested temperatures.

AZ-2000-IECW:
- no significant charging was measured due to the high conductivity of the material.

AZ-2000-IECW presents the higher bulk conductivity followed by Z-93C55 and PCBE is the least conductive.

MLI - samples

2 proposed stacks used for the **MLI outmost layer**.

- germanium coating topside /
1.6 mil (40 µm) 160 XC Black Kapton /
vapour deposited aluminium (VDA) coating backside
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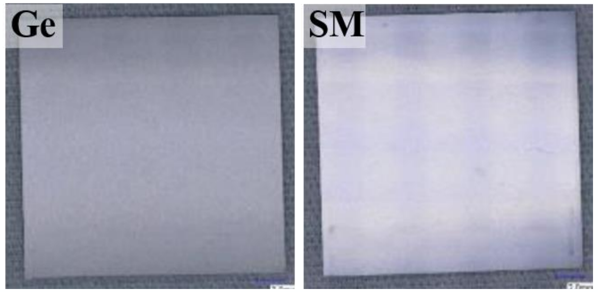
7 samples per type of stack including 5 ageing variants.

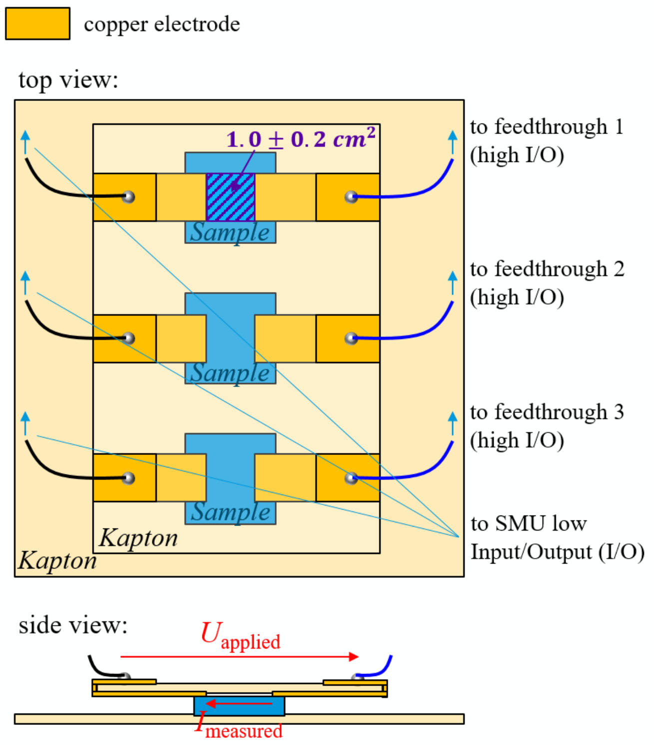


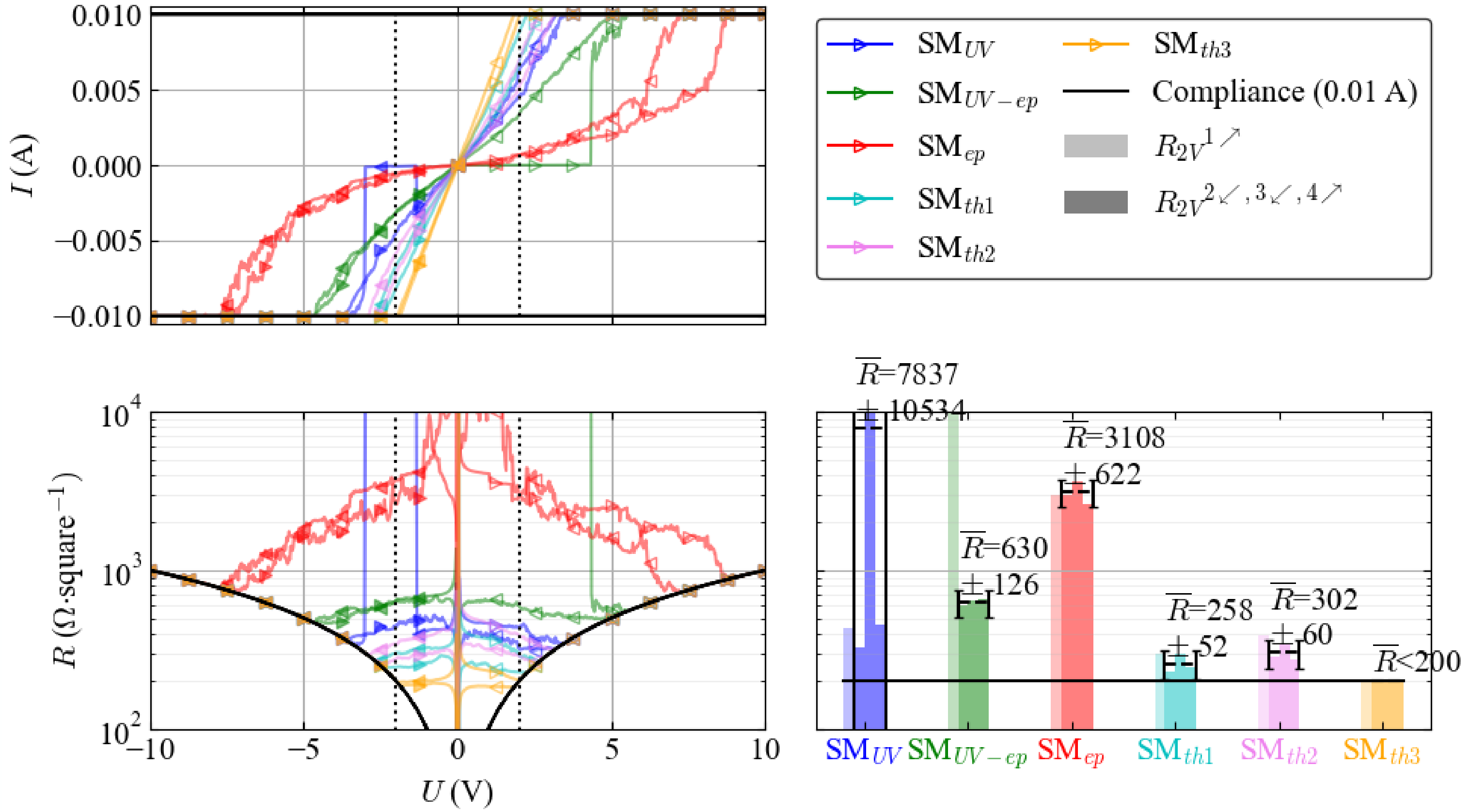
ID	Thermal cycling	UV/VUV	Particle irradiation
pristine	none	none	none
UV		7000 ESH	
UV-ep			· 400 keV electrons · 45 keV and 240 keV protons
ep		none	
th1	100 cycles from -230°C to 230°C	none	none
th2			
th3			

MLI – on-surface DC resistance

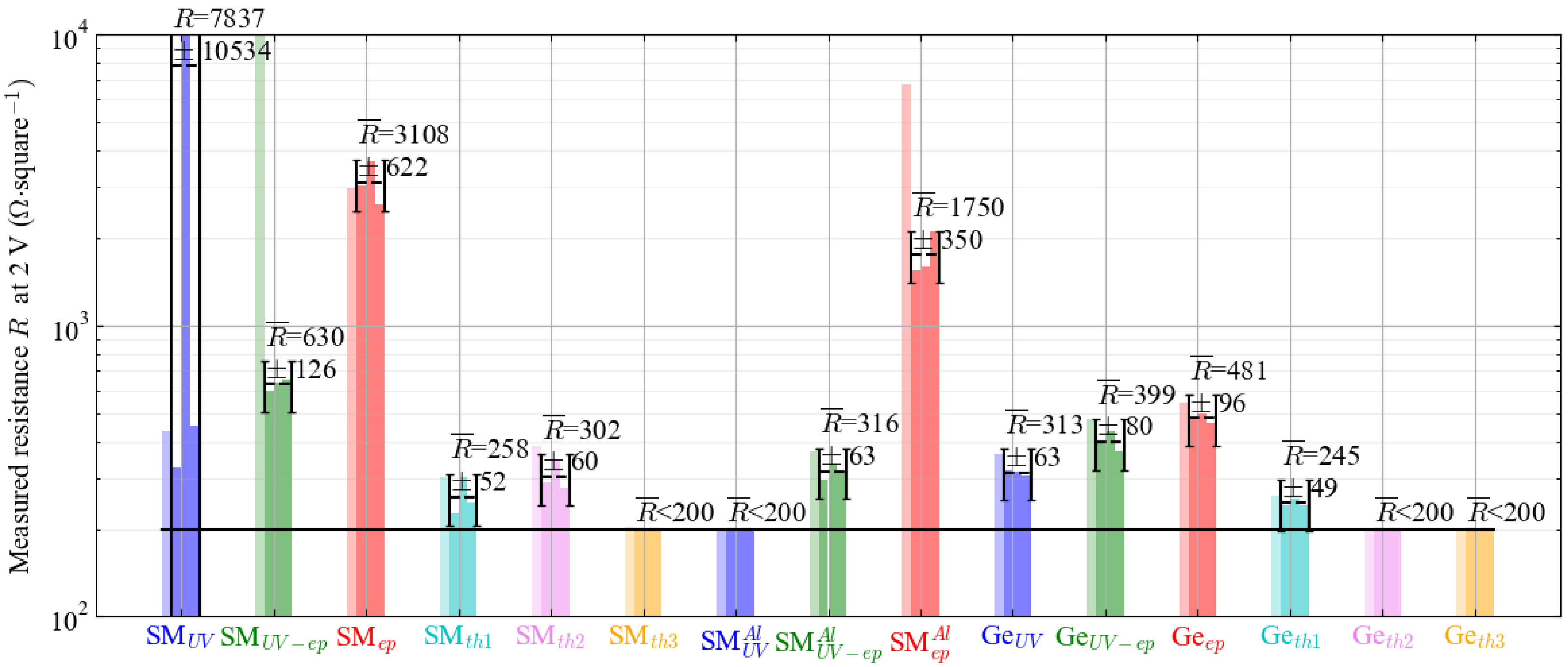
Using **SPD** method, **no significant charging** was measured due to the high conductivity of the material.
On-surface DC resistance measurement at RT.

- Applied voltage swept from 0.000 V to U_{max} = 20.025 V to U_{min} = -20.025 V to -0.025 V.
- 1 s delay time between each data point measurement (dU/dt = 1.5 V·min^{-1}).
- SMU compliance to 0.010 A to protect the foil sample from high power damages.



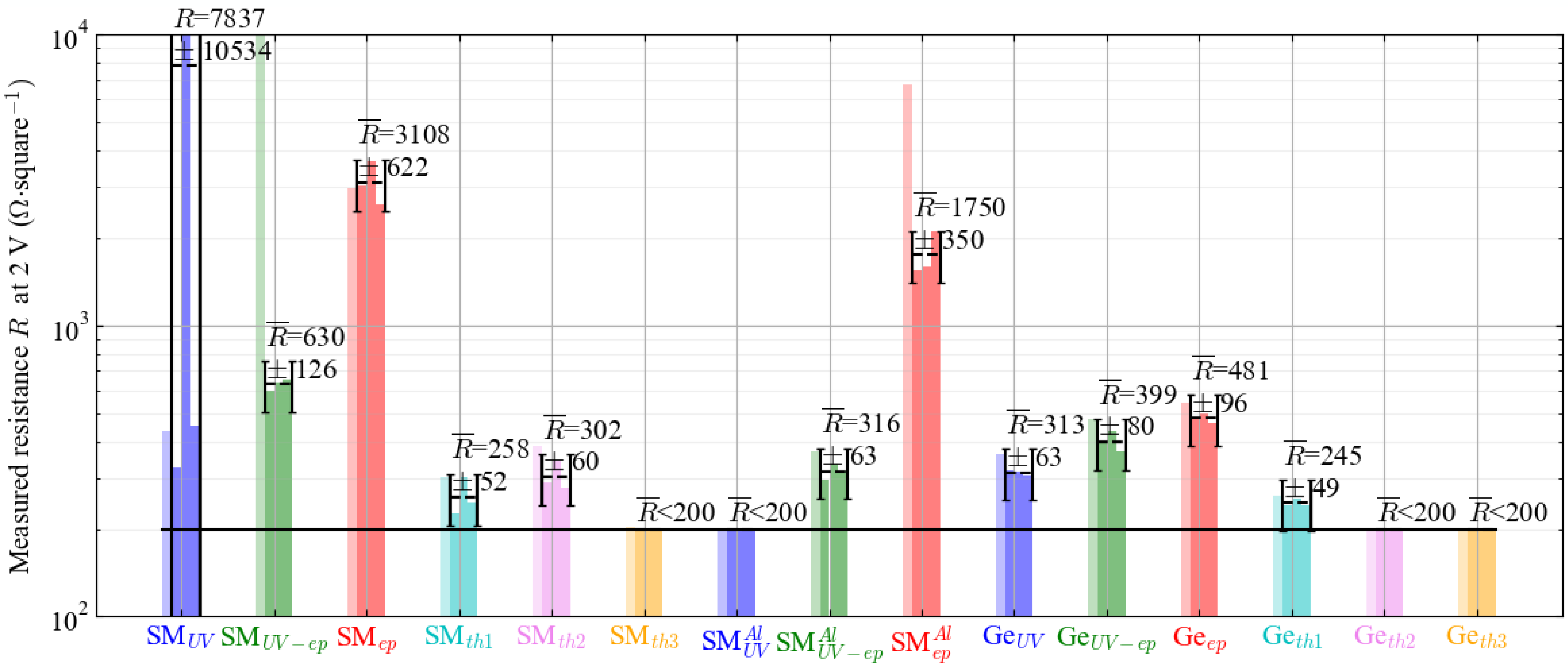


MLI - results



- Data are particularly noisy for the SM samples' set (effect of the SM stack or to a poor electrode-to-StaMet contact)
- Aluminium (instead of copper) contacting is more JUICE spacecraft representative
- ➢ SM_{UV}, $SM_{UV\text{-}ep}$ and SM_{ep} were measured again with UHV aluminium foil covering the electrodes contact area.
- On-surface DC resistance of samples with R_{2V} < 200 Ω.square^{-1} could not be determined because of the test set-up's compliance on the current.

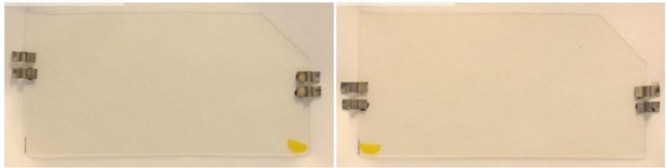
MLI - results



- UV and particles aged samples' results are less scattered for Ge (between 313 Ω.square^{-1} and 481 Ω.square^{-1} at 2 V) than for SM samples (from <200 Ω.square^{-1} to 1750 Ω.square^{-1} at 2 V with aluminium contact).
- Samples that experienced thermal cycling all presented on-surface DC resistances at 2 V below 302 $\Omega\cdot$square^{-1} for SM and below 245 $\Omega\cdot$square^{-1} for Ge.
- Globally it is observed that thermal cycled samples show a lower resistance than the particle aged samples.
  - ➢ $R\ SM_{th} < R\ SM_{UV} < R\ SM_{UV\text{-}ep} < R\ SM_{ep}$

Solar panels – cover glass coating

ITOao2 ITOao5



ITO coated CMG cover glass:

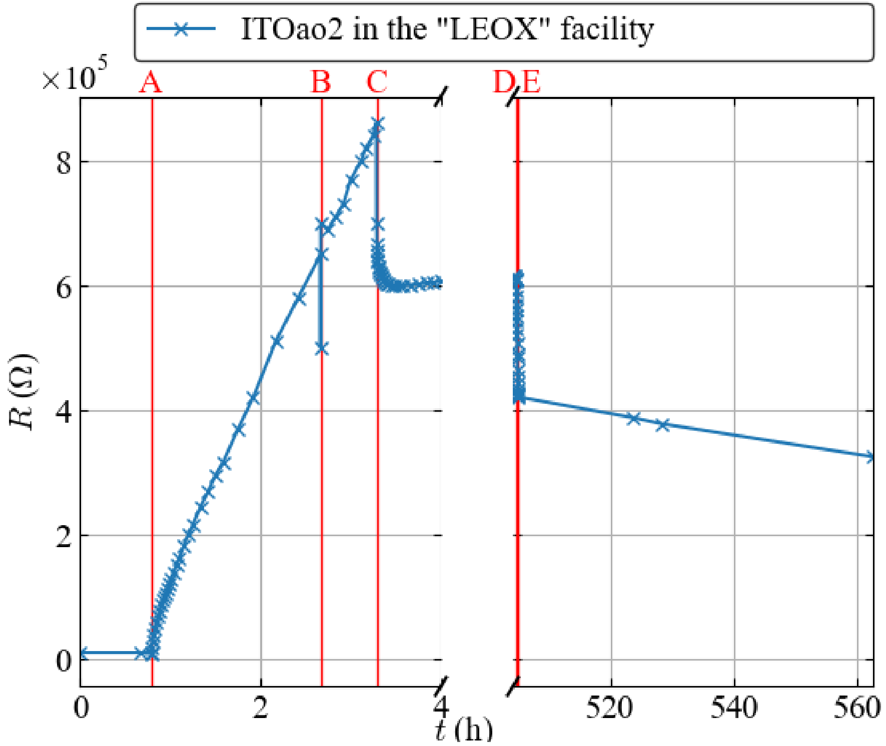
2× samples exposed in the ESTEC "LEOX facility".

- total ATOX mean fluence: ITOao2 = 2×10^{19} atoms·cm^{-2}
  ITOao5 = 5×10^{19} atoms·cm^{-2}

~ expected after 170 days orbiting Ganymede

LEO ATOX energy distribution with a mean kinetic energy of 5 eV.

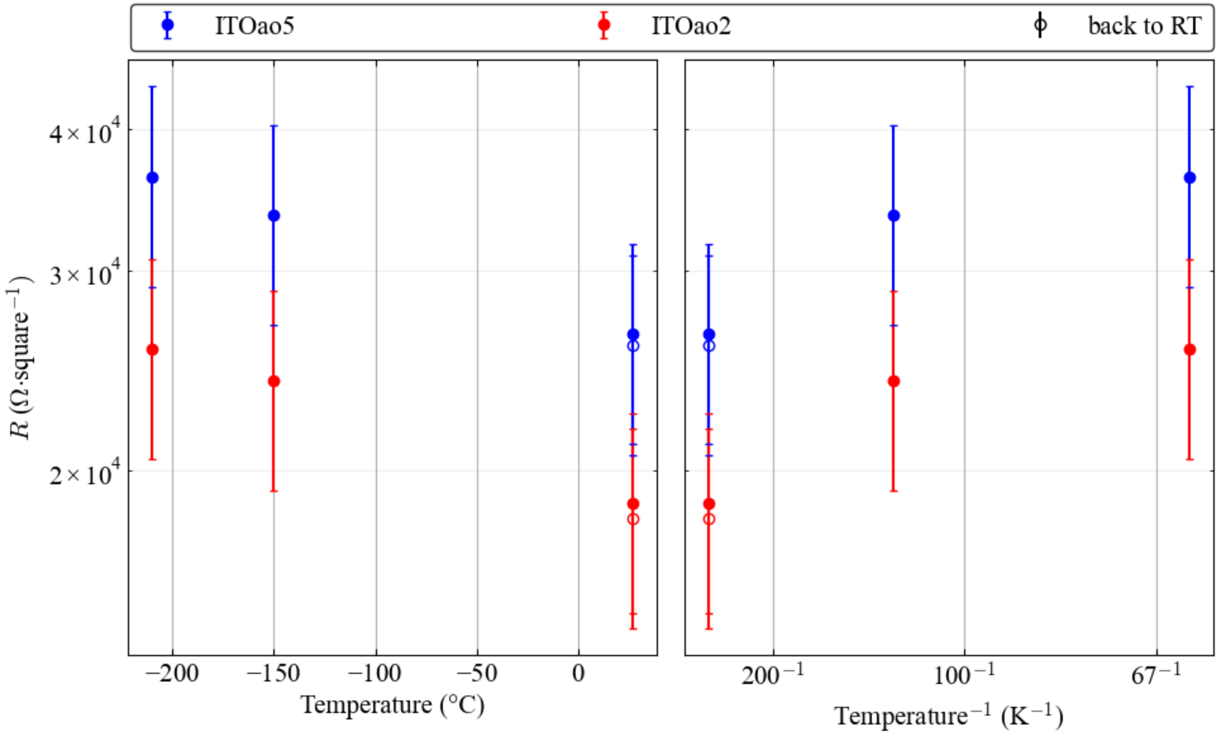
- expected spacecraft velocities from 4.5 km·s^{-1} and 7 km·s^{-1} similar to 7.8 km·s^{-1} in LEO.



Interconnects on samples' extremities for **resistance R during exposure**:

- From t = 0 h, the sample is in vacuum.
  - higher resistance than in atm. (water outgassing)
- A = start of ATOX exposure.
  - monotonous increase of the resistance with the fluence
- B = ATOX shut for ~ 1 min.
  - R drops, partial desorption of ATOX ?
  - R climbs back to value before shutting (+ slight overshoot) when exposed again (quick re-adsorption ?)
- C = ATOX stopped after 2.5 h of exposure.
  - Stable degraded R after a drop (~100× pristine) so erosion or oxidation
- [D to E] = after ~500 h in vacuum, chamber vented back to atm. during ~0.5 h.

Solar panels – cover glass coating



On-surface DC resistance method was applied at **end of test** (risk of damaging the brittle surface) for a quantitative comparison between ITOao2 and ITOao5.

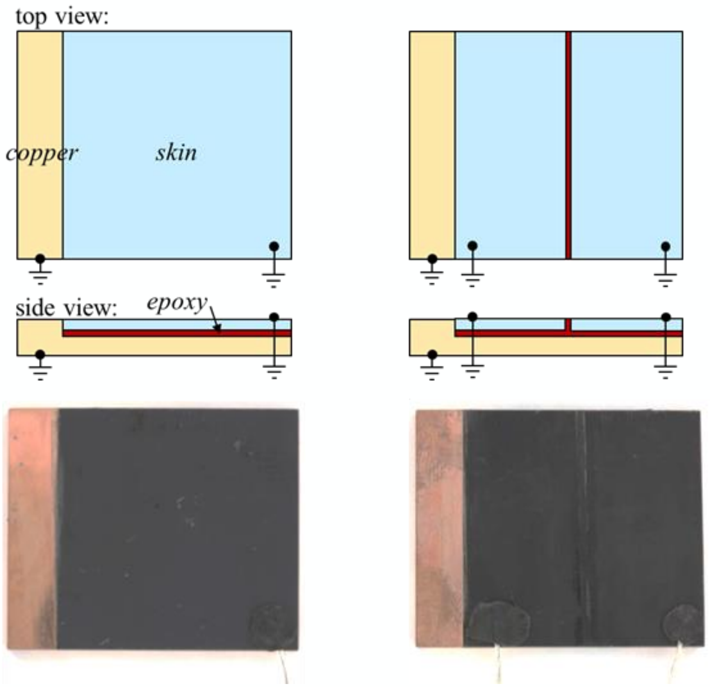
- I-V curves (not illustrated) ohmic and without hysteresis within 0.100 V to 10 V.
- on-surface DC resistance increases when cooled down.
- Albeit uncertainty bars overlay, ITOao5 seems to show higher resistances than ITOao2 up to a difference of ~10 × 10^3 Ω·square^{-1}.

Solar panels – rear side

2× samples of 6-ply rigid array Mk4 **CFRP skin co-cured with Black Kapton** (DuPont Kapton 200RS100)

- 1 plain piece of skin
- 1 with butt joint (necessary to cover the whole panels surface) letting epoxy outflow appearing

Both grounded on the top surface.



Charging after electron exposure was **only** measured on **epoxy outflow at the butt joint** level.

- Co-curing rear side skin with Black Kapton and the grounding method is conductive enough to drain impinging electrons.
- Epoxy used to juxtapose the several coupons of skins presents a charging risk.
- ➢ Any outflow should be covered with conductive material to mitigate any parasitic surface potential on the rear side of JUICE's solar wings.

Conclusion

JUICE material charging investigations with **resistance**, **on-surface DC resistance** and **surface potential decay** methods:

Thermal white coatings:
- AZ-2000-IECW intrinsic bulk conductivity > Z-93C55 > PCBE.
  - ➢ PCBE coating rejected from use on JUICE in favour of the 2 other coatings (pending validation for some instruments).

MLI outmost layers:
- On-surface DC resistance on germanium/1.6 mil 160 XC Black Kapton/VDA & StaMet/1.6 mil 160 XC Black Kapton/VDA.
- Thermal cycled samples on-surface conductance > UV exposed > UV exposed plus particle aged > particle aged.
  - ➢ charging JUICE's requirements were met for all the MLI samples.

Solar panels:
- Significant surface potential after electron exposure on a representative butt joint used to allow the entire rear side coverage.
  - ➢ Butt joints will be covered with Black Kapton.
- Surface resistance of ITO coated solar cells' cover glass 2 orders of magnitude higher after ATOX.

Few investigations are still on-going.

Work to be published in CEAS Space Journal.

Thanks for your attention, Bruno.Delacourt@esa.int.