DEFENCE AND SPACE

Solar arrays for Jupiter missions
Europa Clipper and JUICE

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AIRBUS

Mission consortia

ESA mission JUICE

- Launch date: 2022
- Prime contractor: Airbus Defence & Space,Toulouse, France

- Solar array contractor: Airbus Defence & Space, Leiden, the Netherlands

- Photovoltaic Assembly: Leonardo Company, Nerviano, Italy
- Solar cells: AzurSpace, Heilbronn, Germany

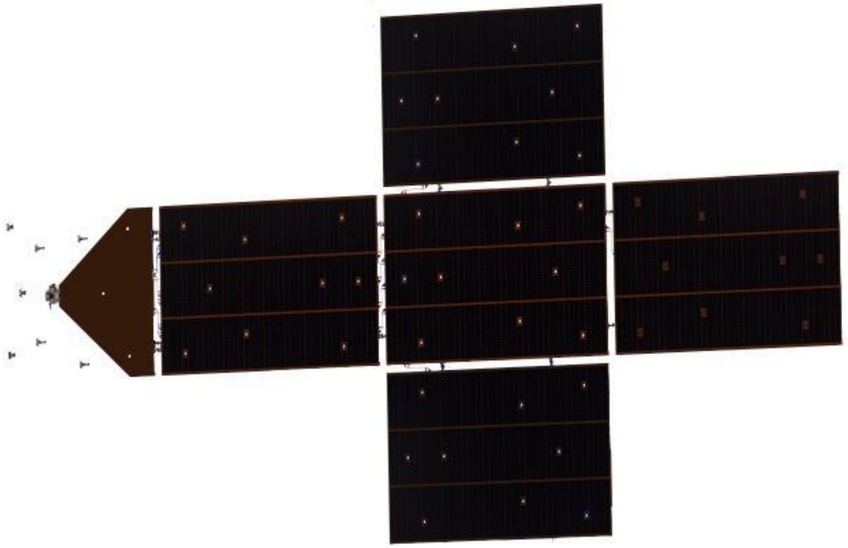
NASA mission Europa Clipper

- Launch date: 2023
- Consortium: NASA/JPL, Johns Hopkins Applied Physics Lab.

- Solar array contractor: Airbus Defence & Space, Leiden, the Netherlands

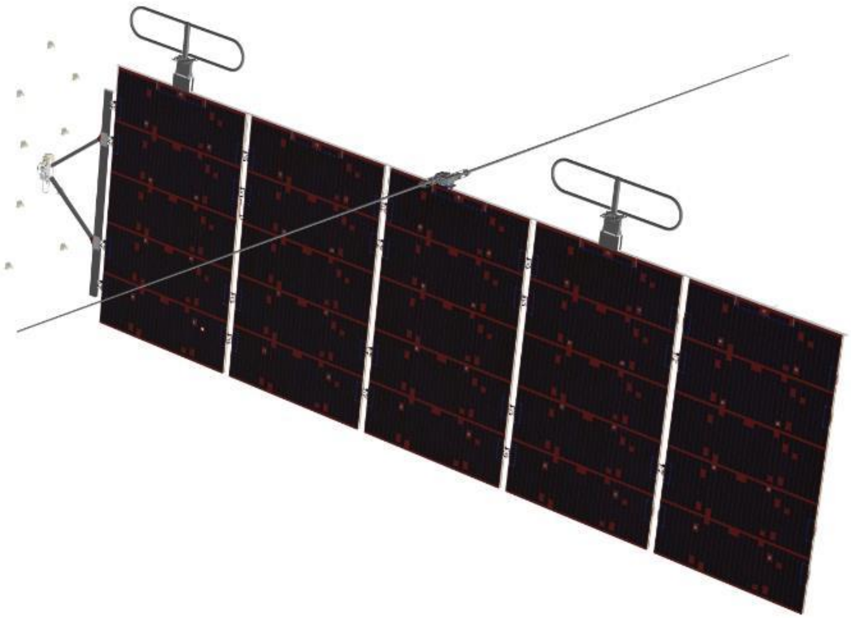
- Photovoltaic Assembly: Airbus Defence & Space, Ottobrunn, Germany
- Solar cells: AzurSpace, Heilbronn, Germany

Background



JUICE
- Azur 3G28 Solar cell characterization covered in ESA study program (TDA)
  - LILT performance
  - Radiation degradation
  - Bare cell and CIC pre-qualification
  - Coupon thermal cycling
- Airbus ARA Mk4 panel substrate technology characterization in B1 phase
  - Radiation hardness of materials
  - Survivability in cryogenic thermal cycling environment
  - Structural properties

Europa Clipper
- Re-use of JUICE technology to the extent possible
- Segment 1 Development phase for confidence testing
  - REASON antenna interface
  - Coupon thermal cycling (different PVA manufacturer)



Mission objectives

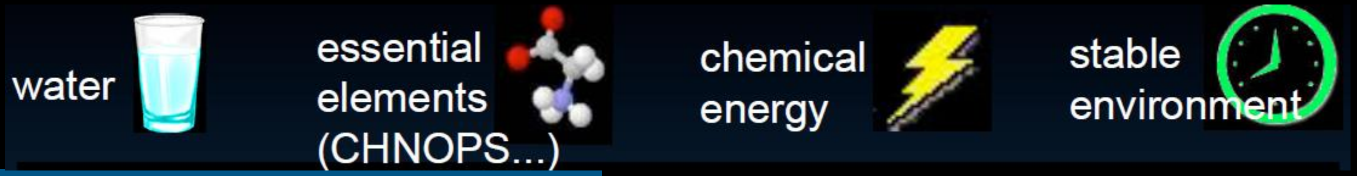
Investigate habitability of Jupiter’s icy moons

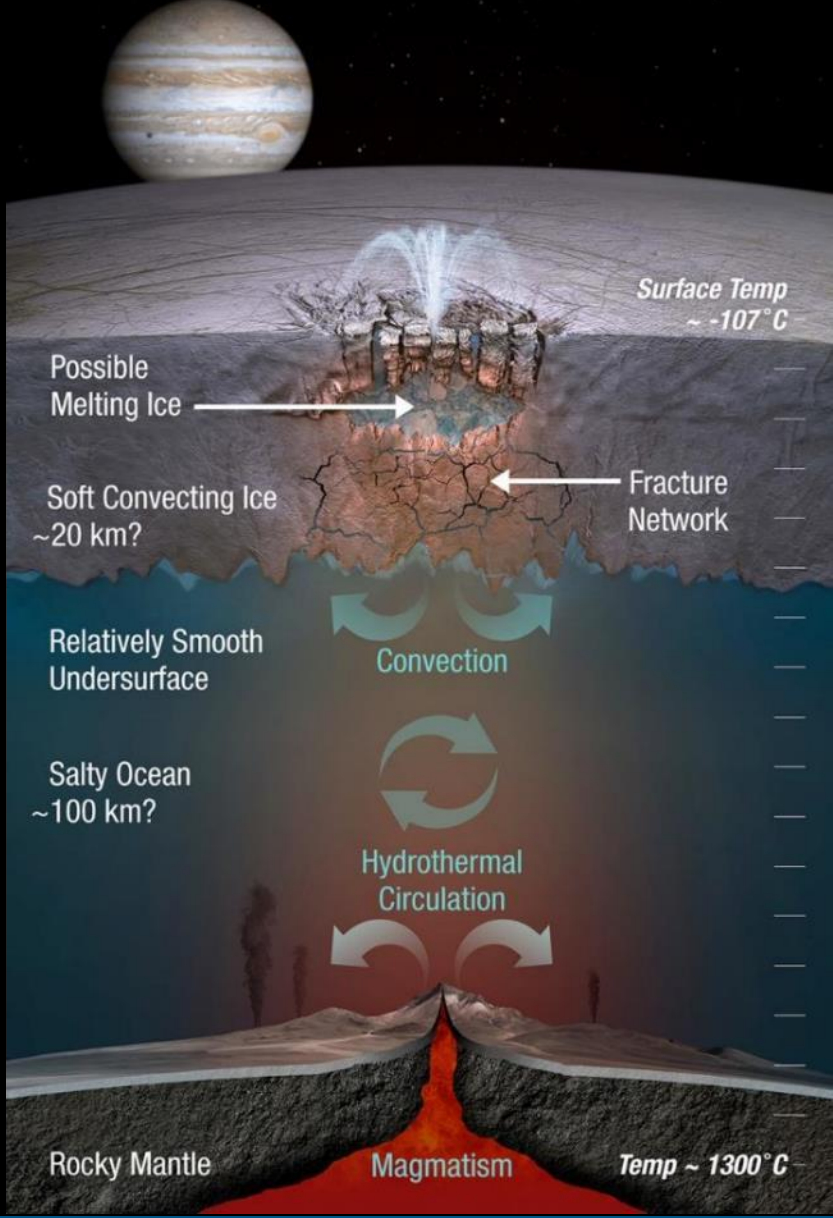
Primary target
Europa Clipper

Primary target
JUICE

Io *Europa* *Ganymede* *Callisto*

Ingredients for life:

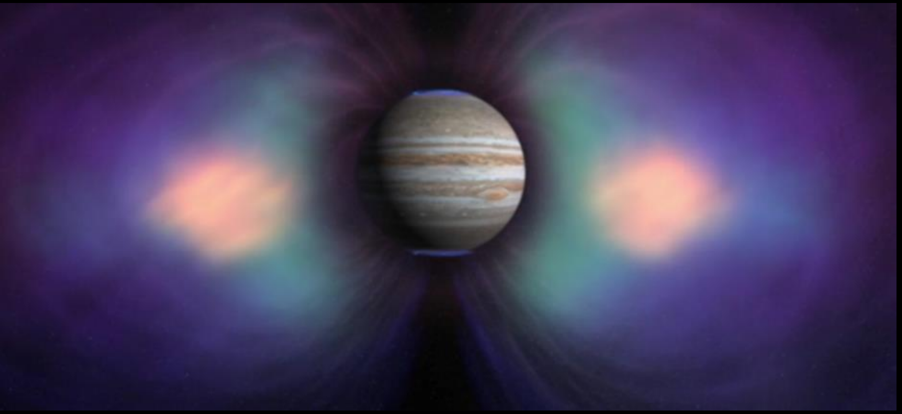


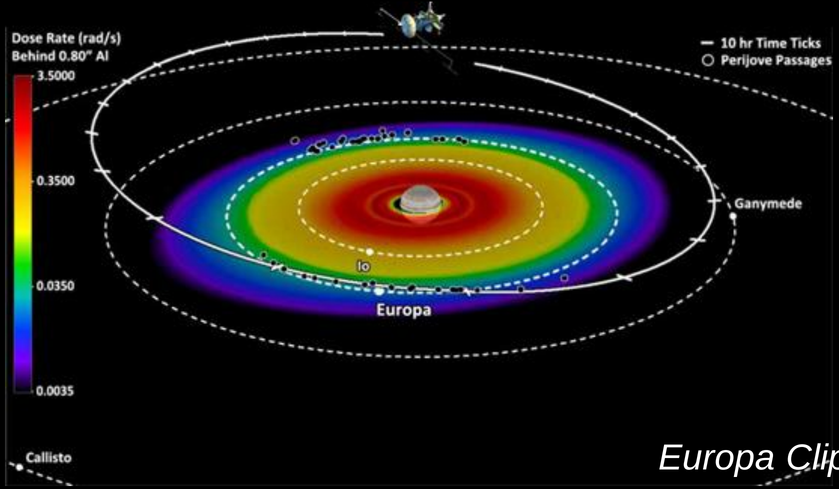


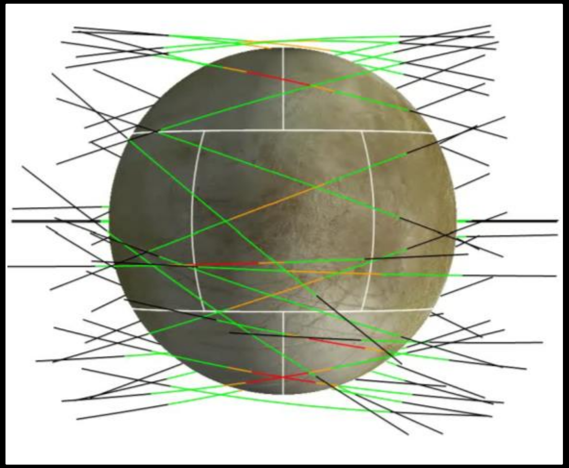
Jovian environment

Radiation

- Europa and Ganymede orbits inside intense radiation belts of Jupiter





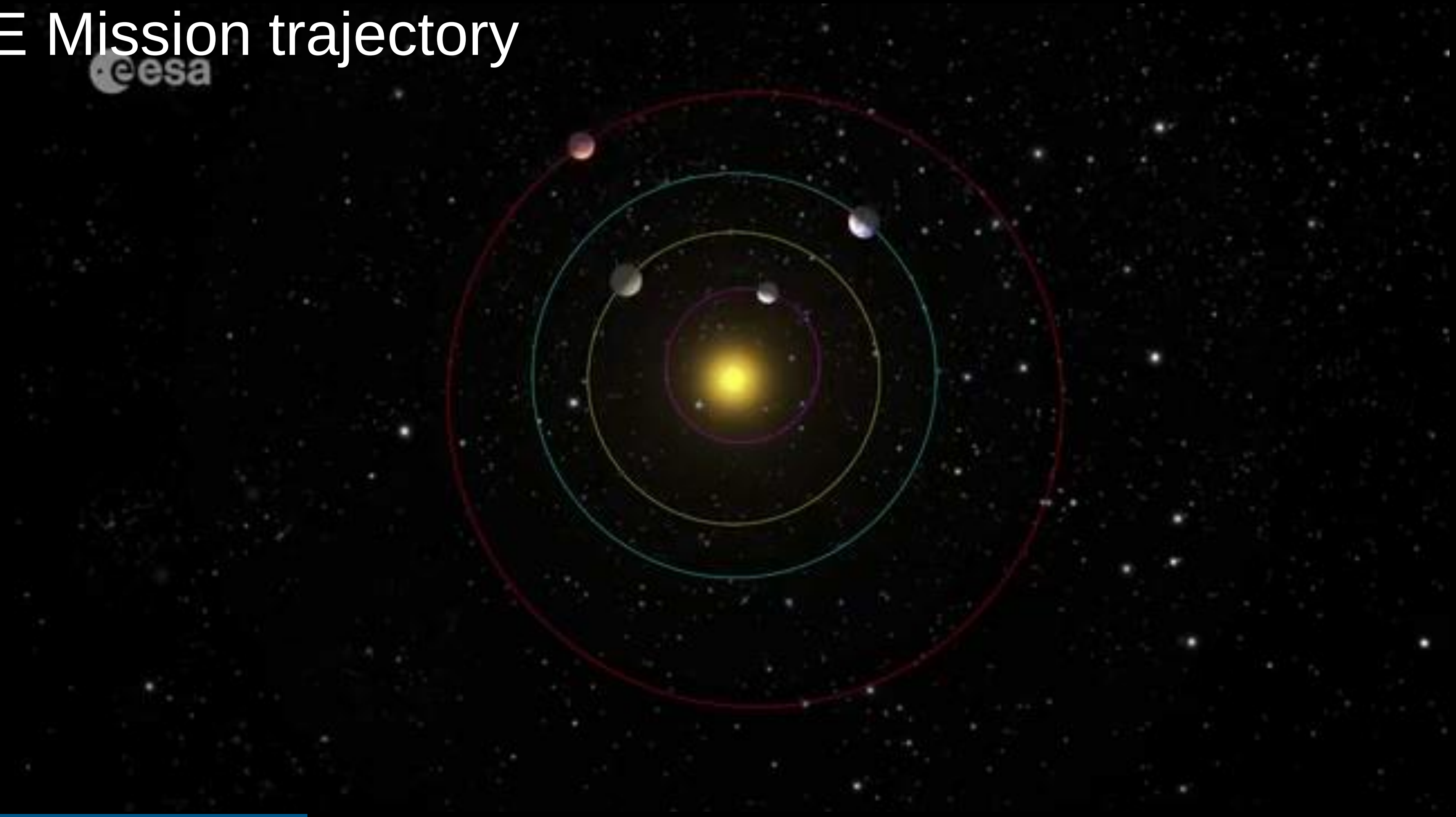


Europa Clipper fly-bys of Europa

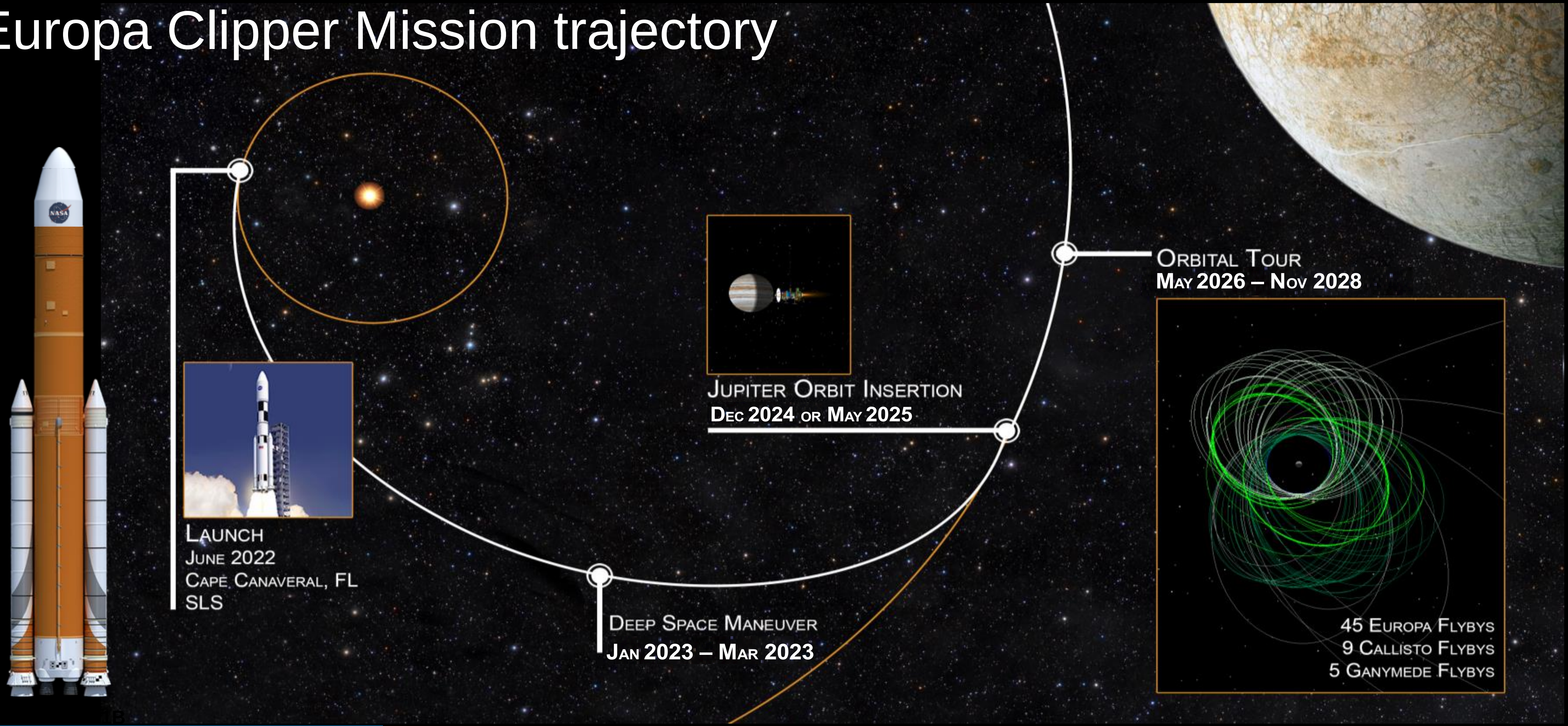
Thermal

- Distance to Sun 5.46~5.03 AU (3.3%~3.7% AM0)
- Solar cell operational temperature ~-130°C
- Cold cycles down to -237°C during eclipse (qualification temperature)

JUICE Mission trajectory



Europa Clipper Mission trajectory



Challenges

mission phase	JUICE	Europa Clipper
Launch	Ok	Structural load of REASON antenna
Deployment	Deployment of lateral panels	Retarding torque from REASON harness
Venus gravity assist	2.2x AM0: high temperature, high current	
Jupiter orbit	Extremely high radiation dose Deep thermal cycling (Jupiter eclipses)	
Ganymede circular orbit insertion	thruster boost (0.22 m/s² at EOL): 400 Nm bending moment at root	n/a
Science phase	• extremely low magnetic signature • uniform surface potential within 1V	• low magnetic signature • uniform surface potential • EMI REASON antenna

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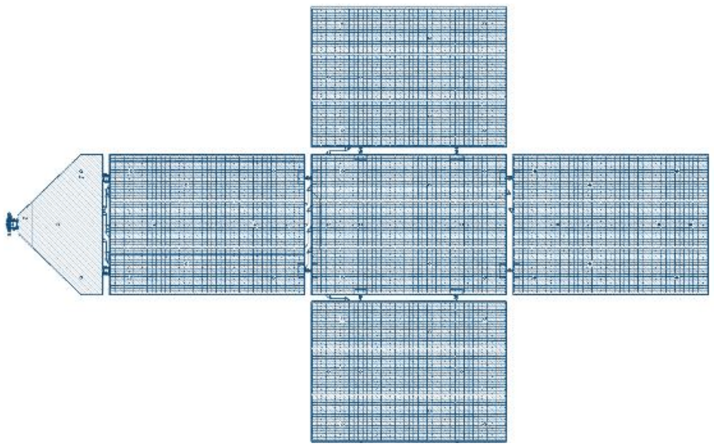
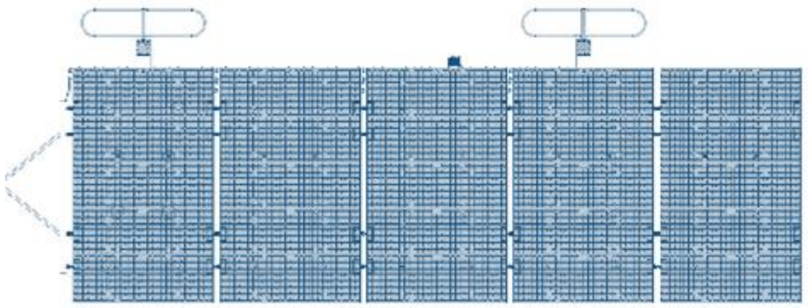
Solar array design





	JUICE	Europa Clipper
solar array area (2 wings)	85 m²	102 m²
panel dimensions	3.45 x 2.48 m	4.13 x 2.47 m
number of panels	2 wings x 5 panels	2 wings x 5 panels
deployed wing length	12.4 m	14.1 m
solar array mass (incl. contingency)	350 kg	571 kg
number of solar cells (Azur 3G28, 40x80 mm)	23,560	28,120
1 MeV electrons (behind 300 µm coverglass)	>2e15 cm^{-2}	>4e15 cm^{-2}
EOL power	766 W (@5.03 AU)	728 W (@ 5.46 AU)

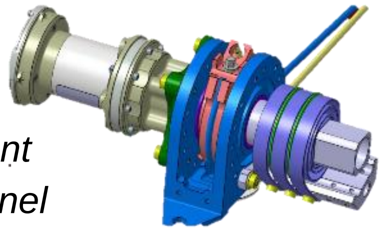
Europa Clipper SA design features

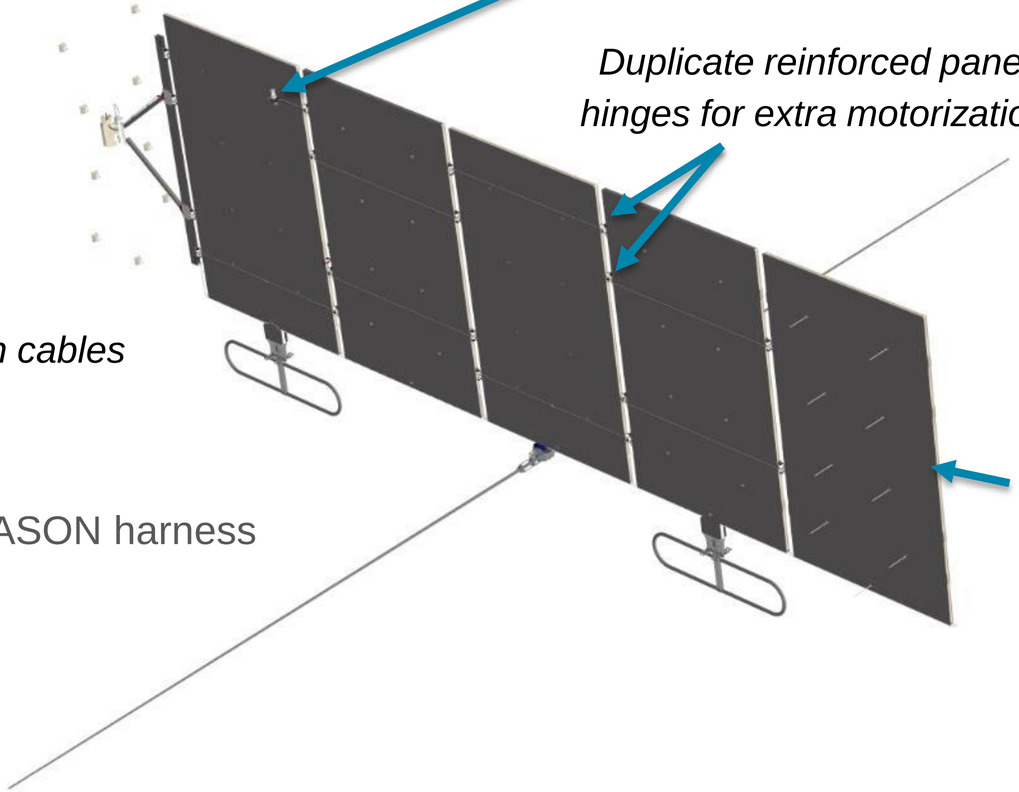
"Standard" ARA Mk4 product family

- CFRP sandwich panels with 22 mm core height
- Passive deployment with spring-motorized hinges
- Synchronisation cables
- Eddy-current damper at root hinge

Europa Clipper mod's

- increased core height for load capability REASON
- 4x higher hinge motorization due to retarding torque REASON harness
- double synchronization cables and dampers





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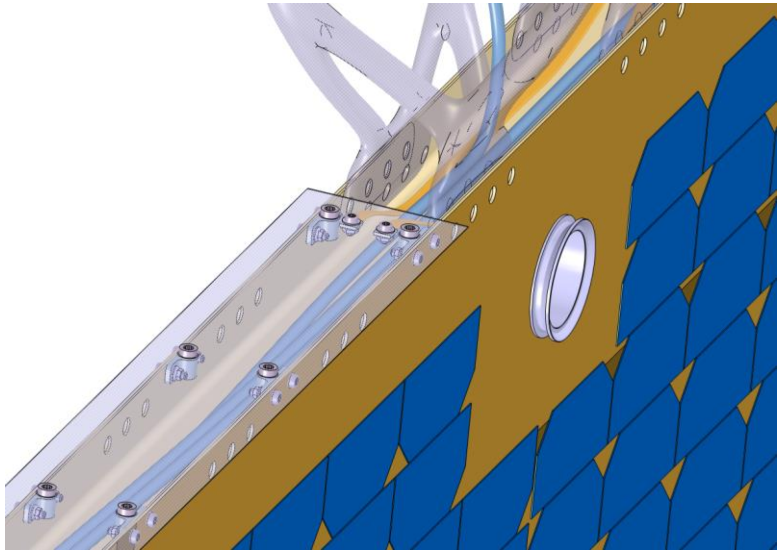
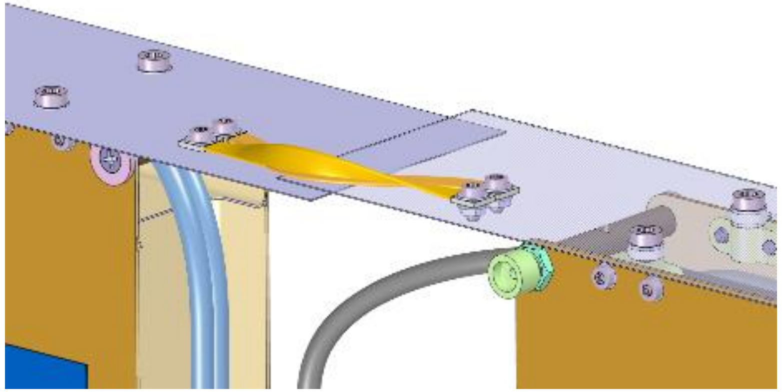
Europa Clipper design features



Harness
- REASON coax cables routed through CFRP C-channels in panel edge
- Panel edge covered with highly conductive ground shield to reduce EMI (No bleed resistors possible)

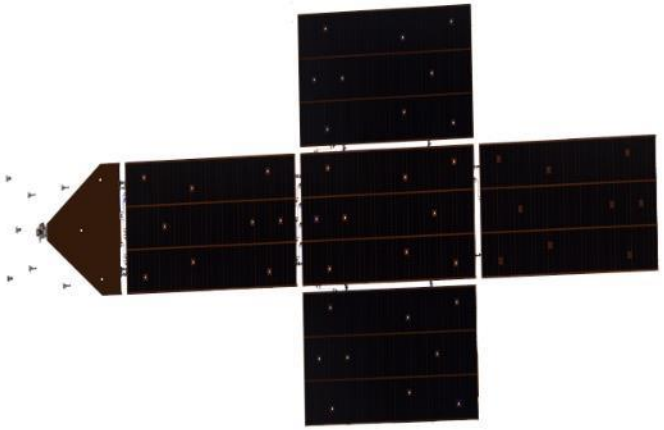
PVA
- Azur 3G28 triple-junction solar cells 40x80 mm
- 300 µm coverglass
- Silicon by-pass diode in cropped corner

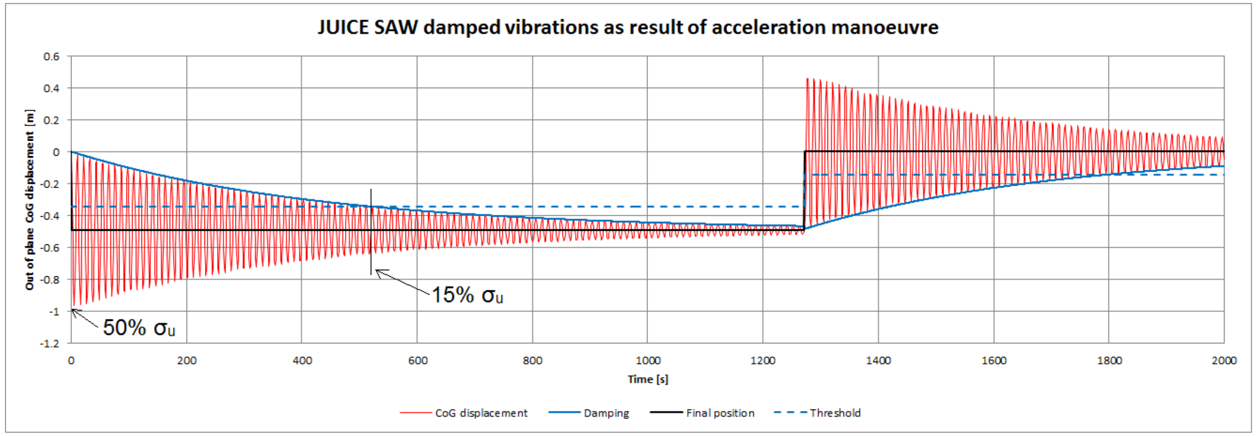


Charge bleeding
- Coverglass grounding network
- Black Kapton on panel rear side

JUICE solar array design features

- One shot deployment using sequencing mechanisms for release of lateral panels
- Boosts at Venus (0.10 m/s²) in hot condition and Ganymede (up to 0.22 m/s²) in cold, after radiation and thermal cycling
- Lateral panels to reduce bending moments at root and increase deployed frequency
- Yoke panel instead of yoke tube to reduce qualification effort





PVA, Charge bleeding

- See Europa Clipper

multi-body analysis of deployment

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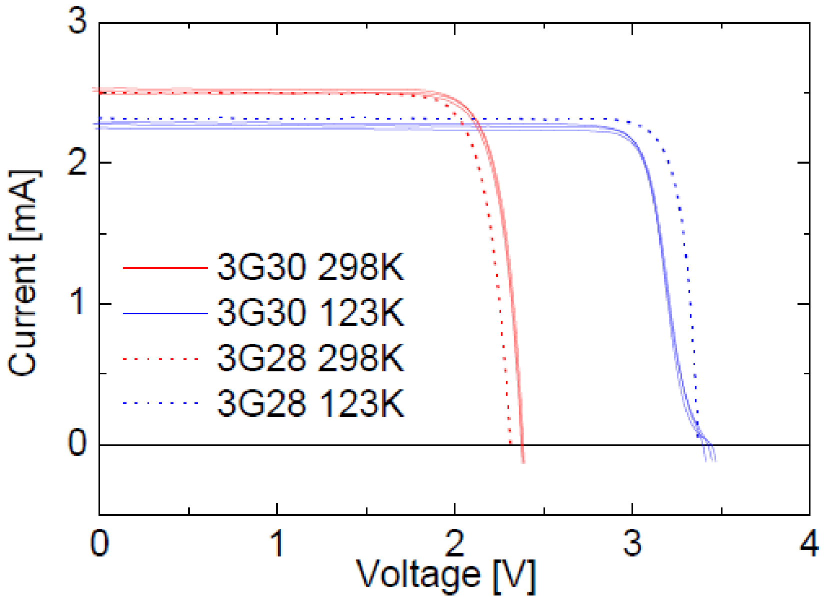
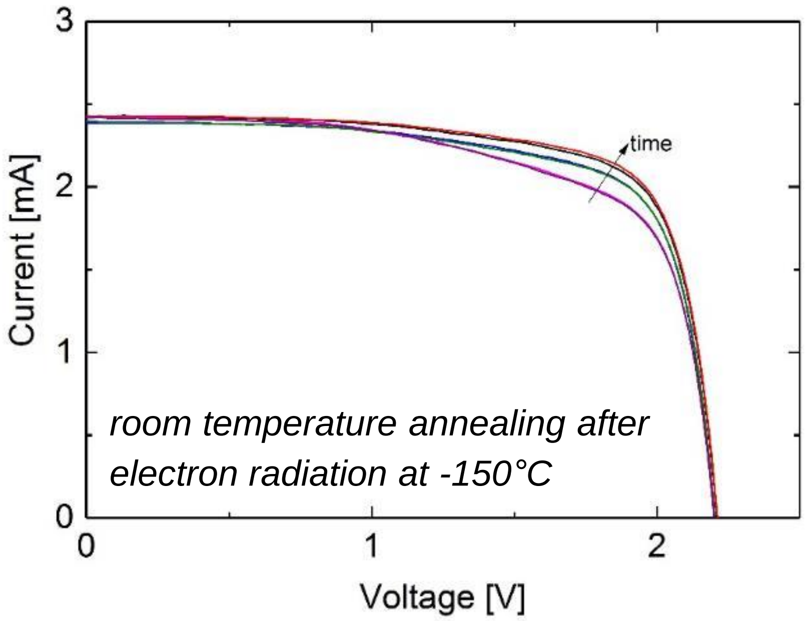
Solar cells

- AzurSpace 3G28 solar cell performs better under LILT than state-of-the-art 3G30

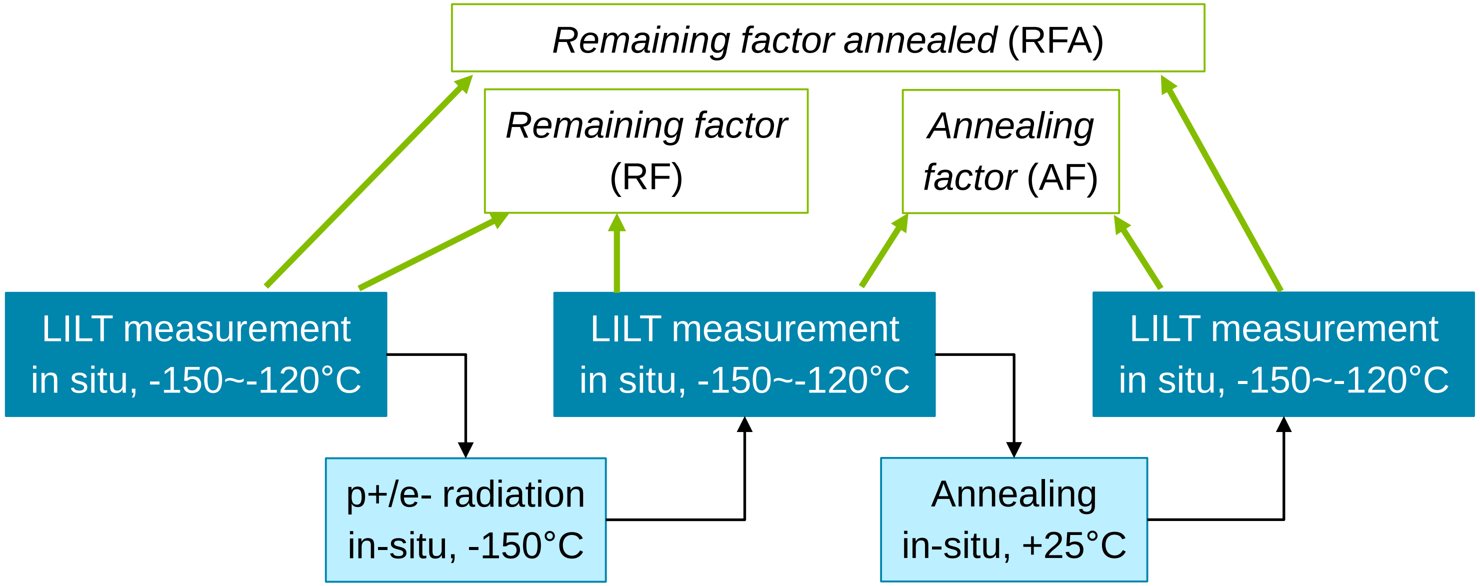
condition	efficiency
AM0, 25°C	28.0%
3.7% AM0, 25°C	25.9%
3.7% AM0, -130°C	34.8%

- Extensive characterization program lead by ESA
  - LILT performance
  - Electron & proton radiation at low temperature (-150°C)
  - Effect of annealing:
    - degraded cells recover at room temperature
    - no recovery possible during the mission (T_{max} = -130°C)
    - no exposure to room temperature allowed during on-ground radiation testing
    - test campaigns at Ecole Polytechnique (France) and ONERA (France)

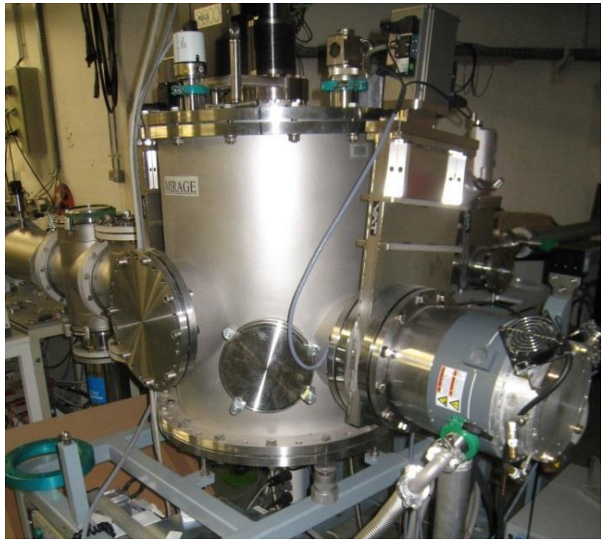




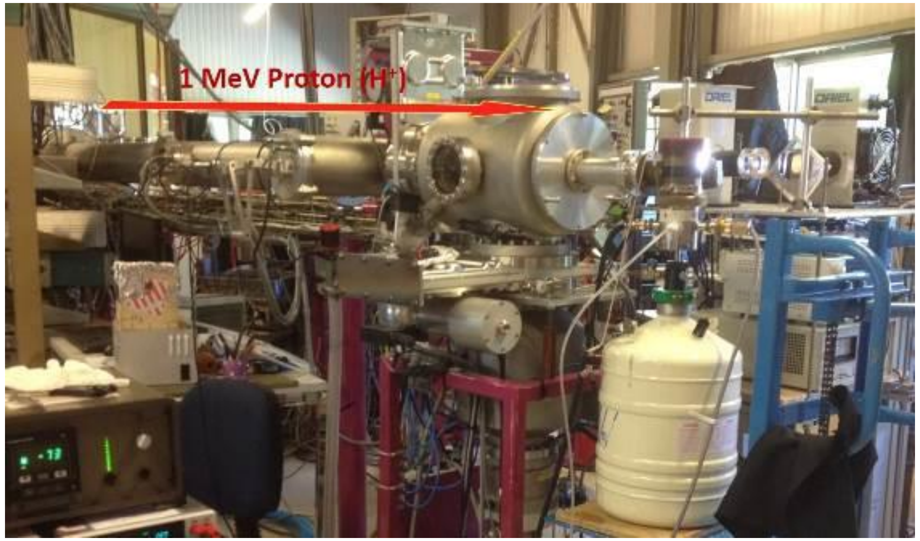
LILT Radiation and annealing tests on Azur 3G28



- Test sequence to determine
  - RF: LILT remaining factors at 3.7% AM0, -120~-150°C
  - AF: Annealing factor at room temperature
  - RFA: LILT remaining factors at 3.7% AM0, -120~-150°C for comparison with AM0 heritage data
  - BOL/EOL temperature coefficients at 3.7% AM0



test chamber ONERA



test chamber Ecole Polytechnique

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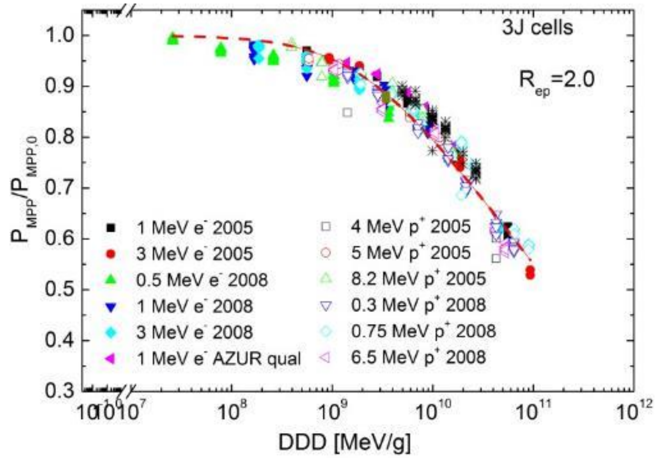
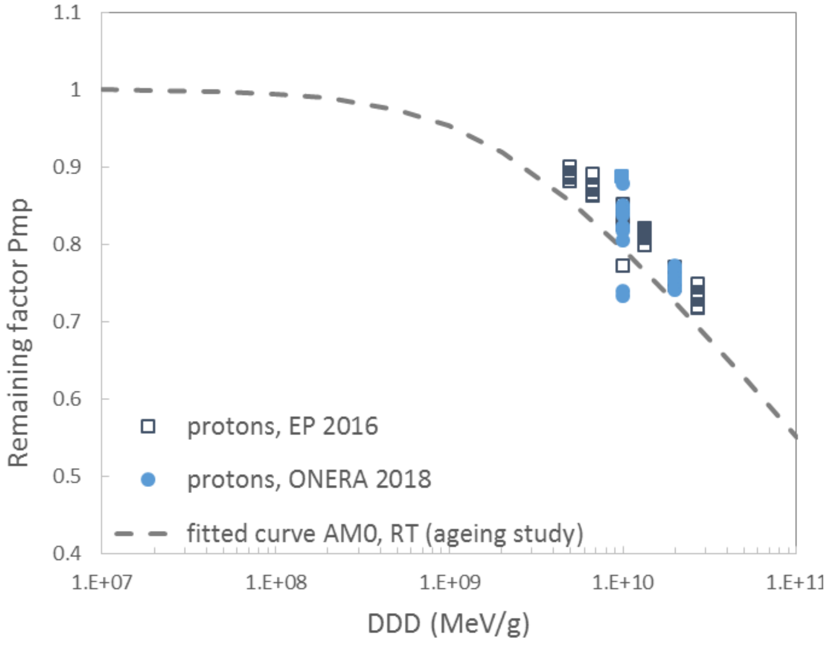
LILT Remaining factors Azur 3G28

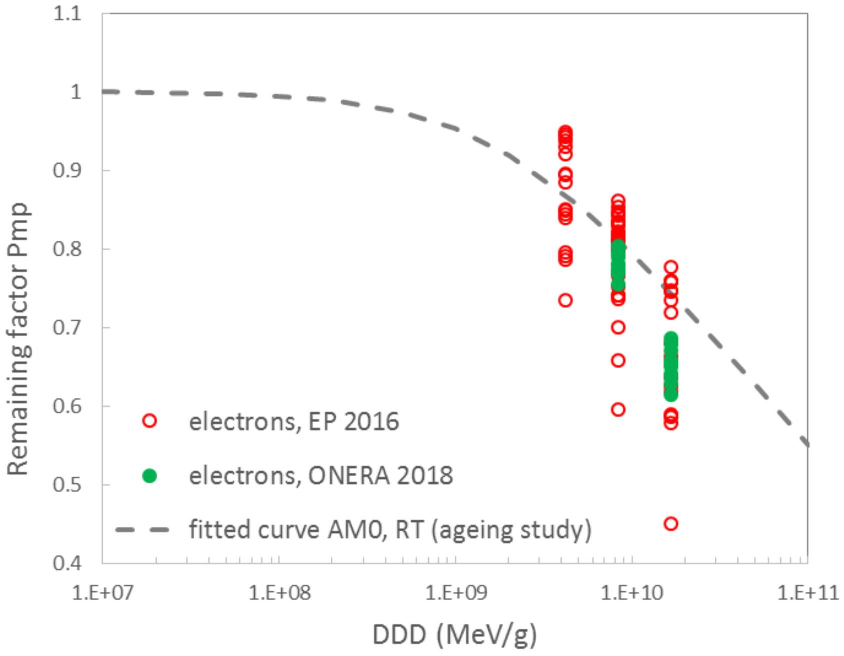


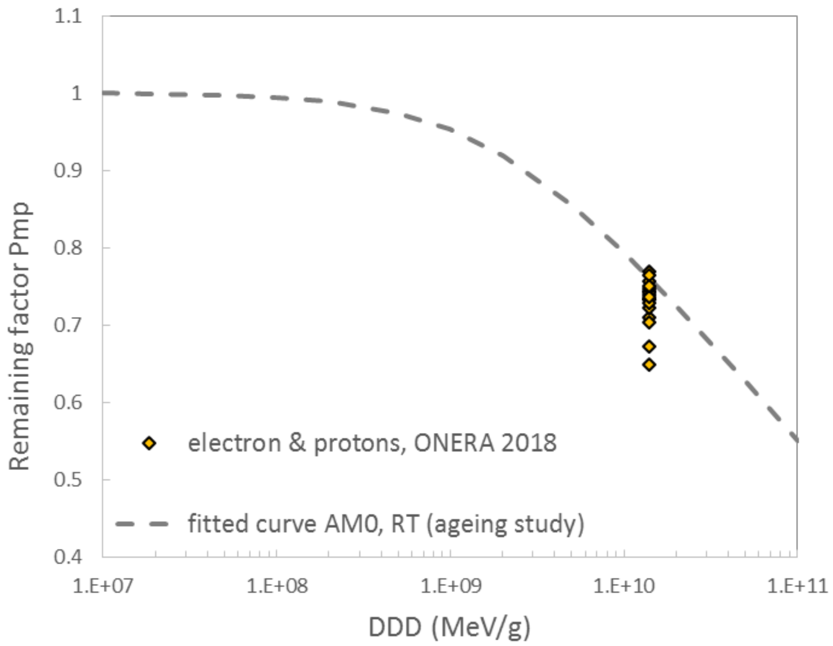
Ageing study 3G28 (AM0, 25°C) (Airbus, ESA)

Remaining factors after annealing (RFA):

- Proton degradation at LILT less than at AM0, room temperature
- Electron degradation at LILT higher than at AM0 and larger distribution
- Combined protons & electrons represent actual mission fluence of JUICE
- All data at 3.7% AM0, -130~-125°C

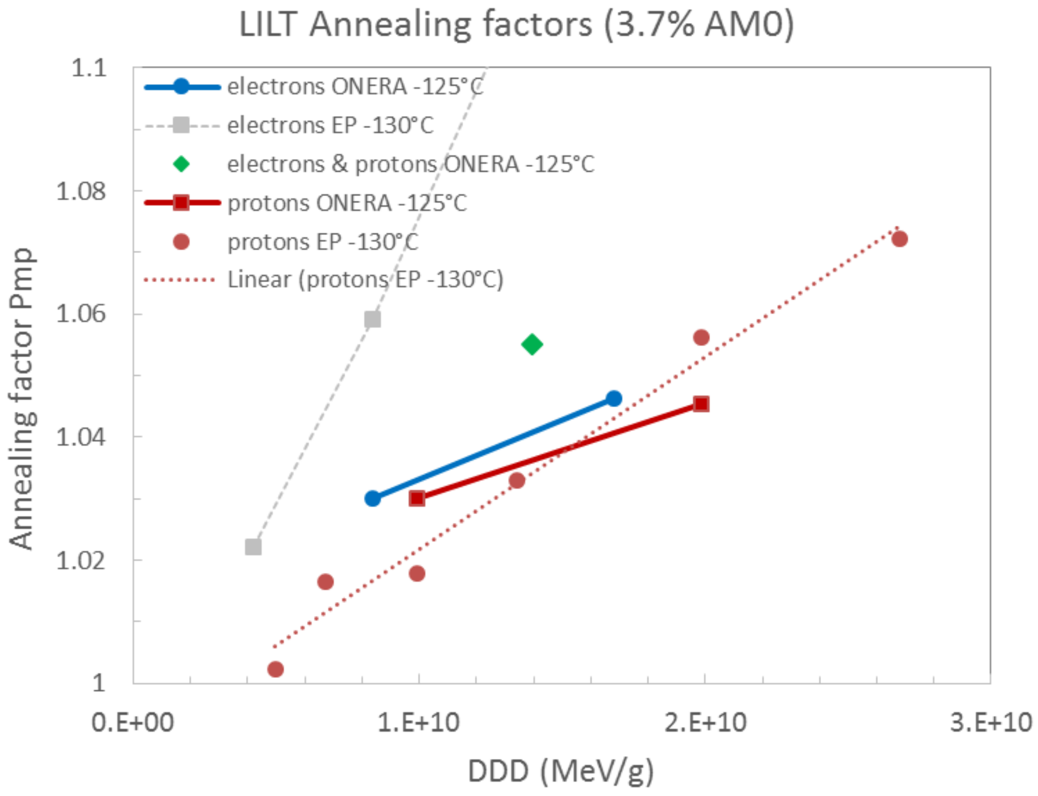






Annealing factors Azur 3G28

- Annealing factors from JUICE TDA study by ESA (EP) and Airbus study (ONERA)
- Combined electron and proton radiation performed representative for JUICE
- AF from electron radiation at EP unstable → discarded
- Annealing factor of 5.5% used in power analysis (from combined electrons & protons)



Radiation tests on materials

- All non-metallic materials subjected to 1 MeV electron radiation test
- Skin adhesive of honeycomb panels tested up to 150 MeV (incl. skin shielding)

- Honeycomb core adhesive failed in the first test

flatwise tensile test result

after radiation in GN_2 and thermal cycling

  - Adhesive degraded under radiation in GN_2 purged bag leaving O2 in the honeycomb cells
  - No degradation under radiation in vacuum
  - Degradation caused by persistent oxygen in honeycomb cells

Cryogenic thermal cycling

JUICE cycling profile	range		no. of cycles			
Life cycle	min. °C	max. °C	PFM/FM	VGA coupons	GOI coupons	EOL (QM/DVT)
PFM/FM acceptance cycles	-180	110	4 (TBC)	4	4	4
	-224	-90	6 (TBC)	6	6	6
Earth eclipses	-180	110		3	3	3
Jupiter moon eclipses 1	-185	-90			40	40
Jupiter moon eclipses 2	-195	-90			45	45
Jupiter planet eclipses	-227	-90			53	106

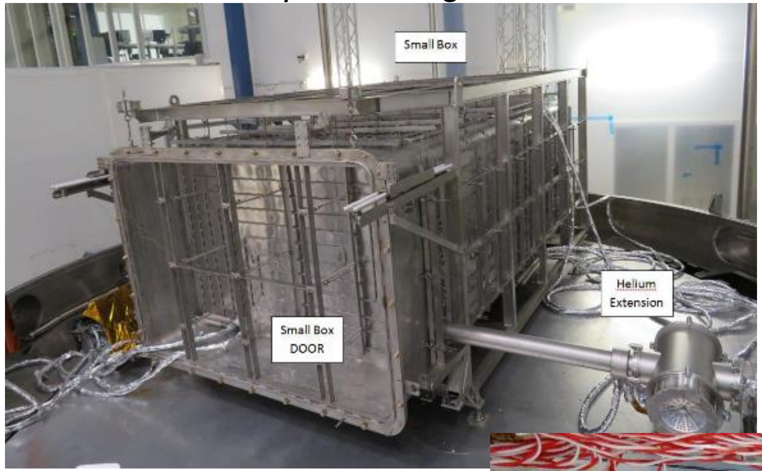
VGA: Venus Gravity Assist
GOI: Ganymede Orbit Insertion

- Both 22 mm and 44 mm thick substrates tested
- Combined DVT/QM panel due to size of cryogenic chamber
- Europa Clipper to be covered in delta test program (-237°C, different no. cycles)

Cryogenic thermal cycling

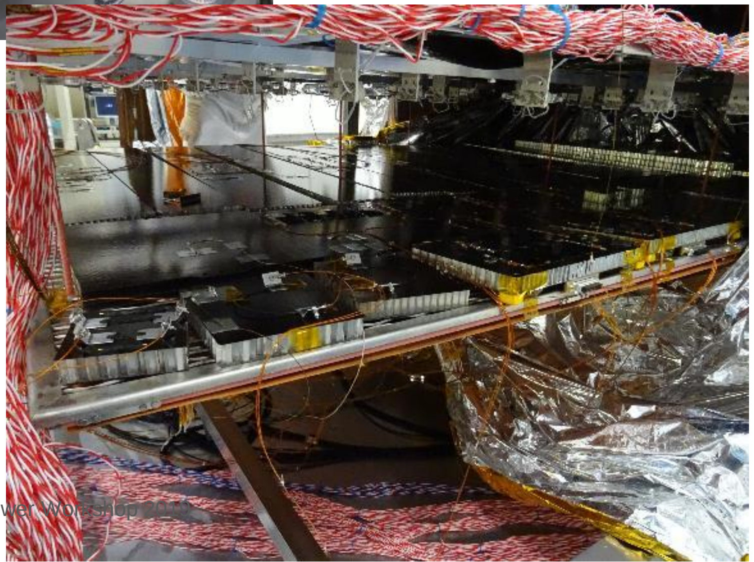
Wide Range Test Facily at CSL (Belgium) for cryogenic thermal cycling

Small box for coupon testing



Large box for panel testing

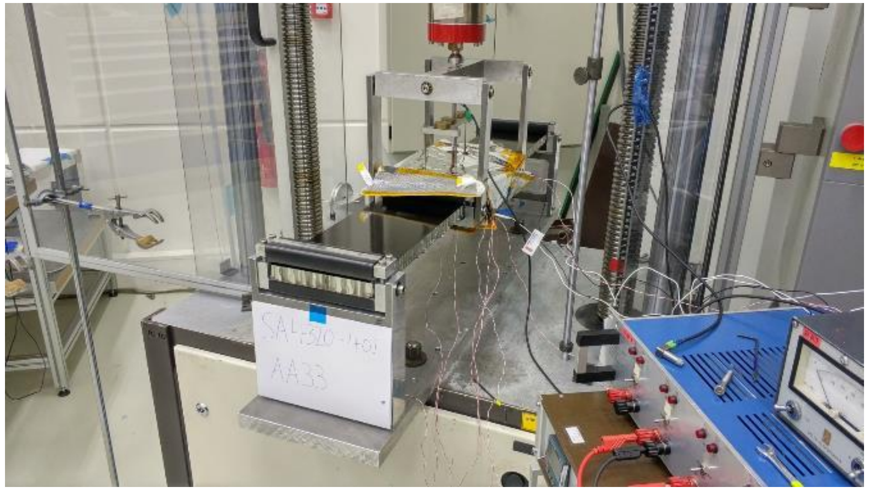
Tray (1 of 2) filled with coupons



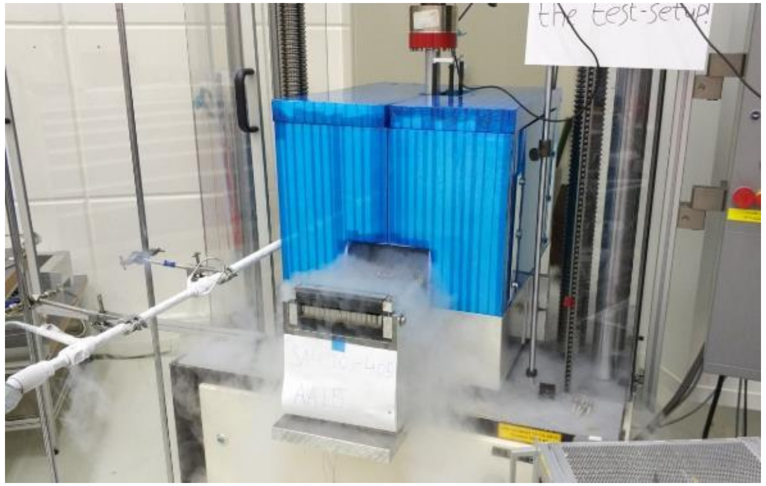
Proto-panel JUICE

Structural properties

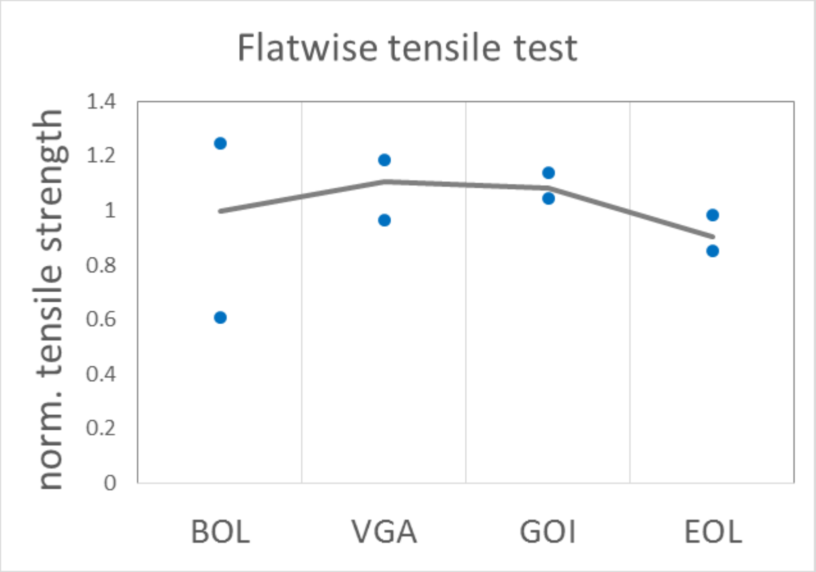
- Properties after (cryo-) thermal cycling
- Tested at in-orbit temperatures
- No structural damage observed

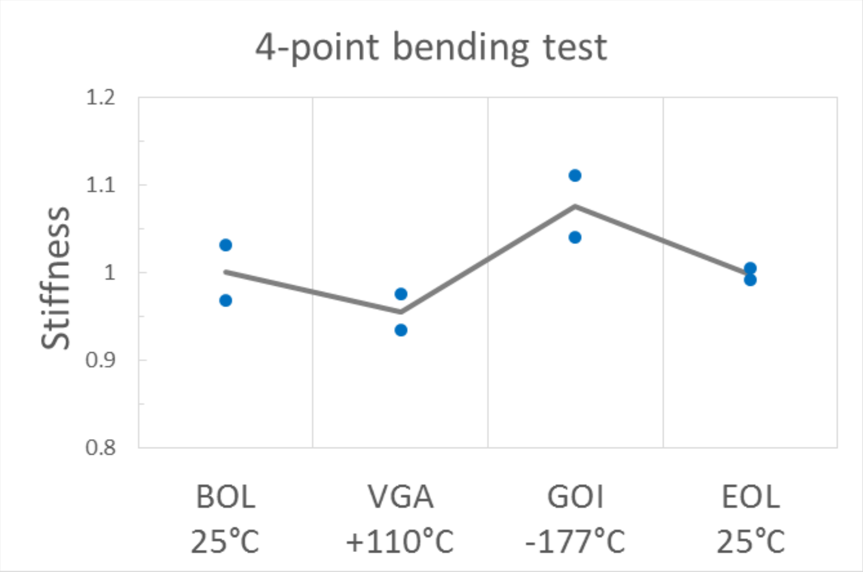


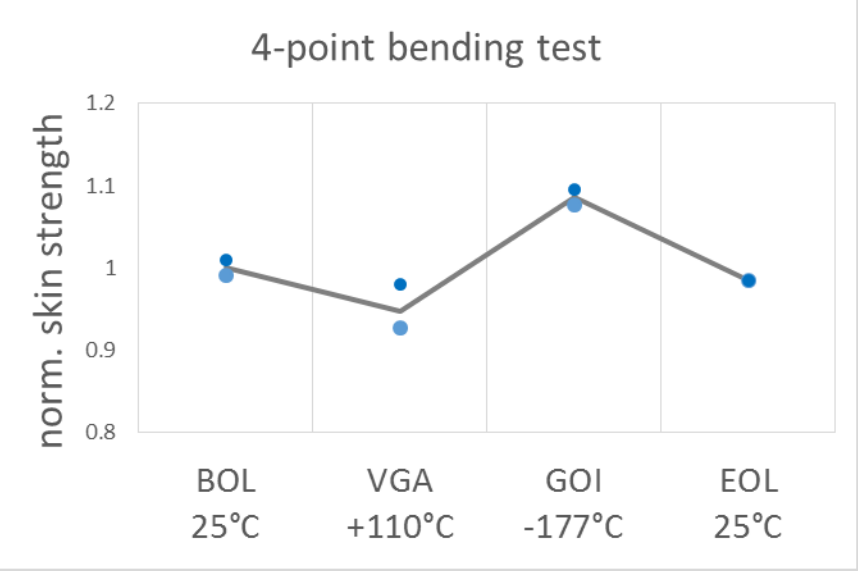
4-point bending test hot



4-point bending test cold







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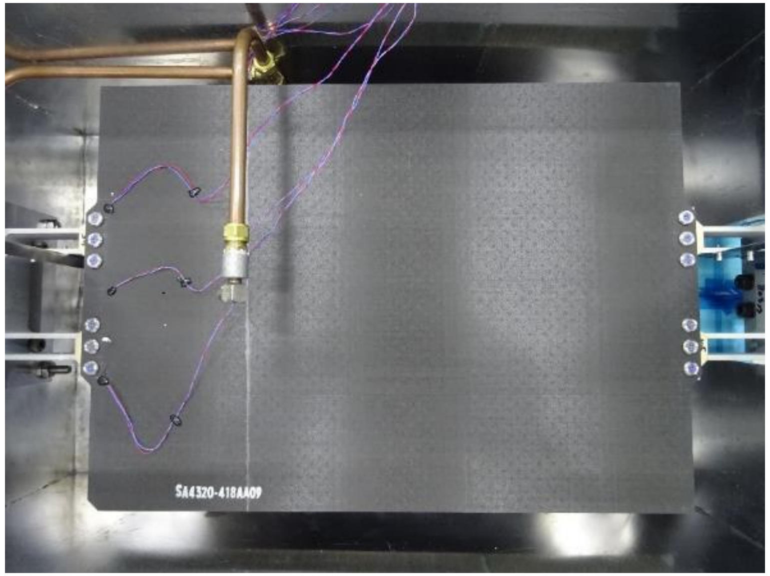
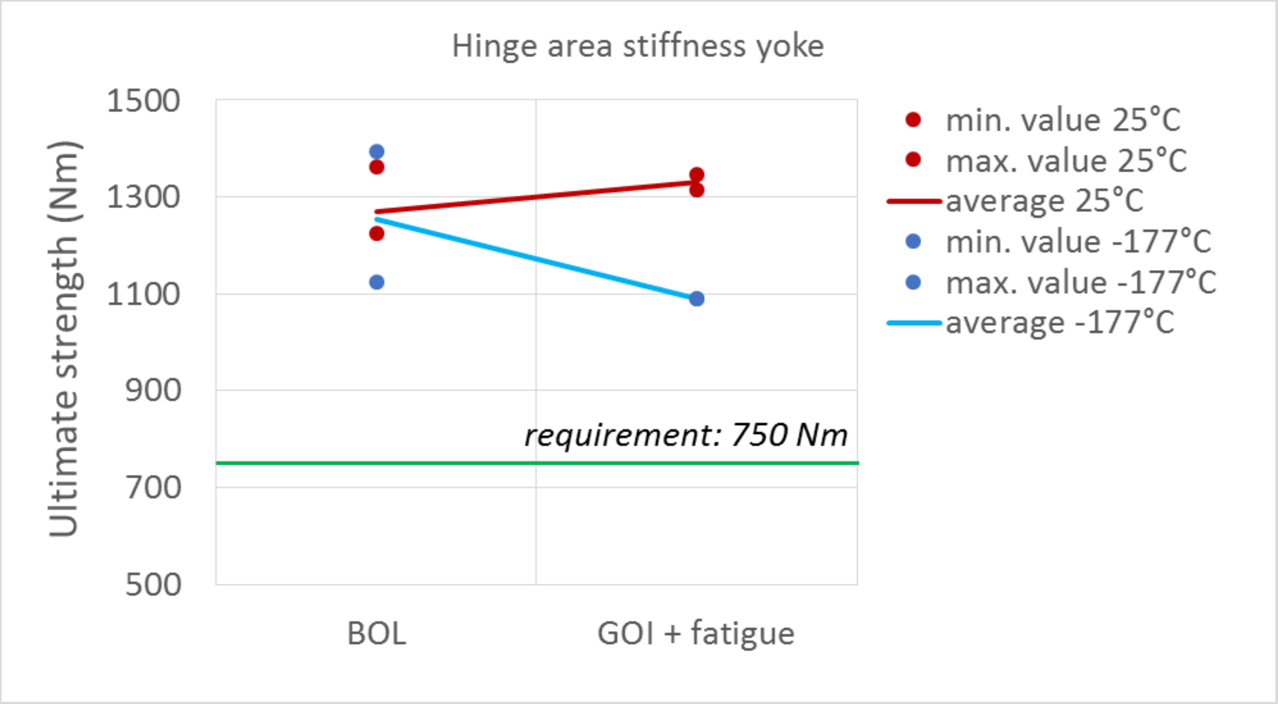
Yoke panel ultimate strength

- Max bending moment on JUICE yoke panel: 400 Nm incl. dynamic amplification or 1.4
- Yoke panel interface to root hinge tested



test sample in strength tester



Magnetic performance

- PVA design rules
  - back wiring of strings to minimize magnetic moment
  - antiparallel string configuration to compensate each other's moment
  - twisted circuit harness
  - non-magnetic interconnects and bus bars

- Mobile Coil Facility (ESA-ESTEC) used for magnetic characterization
- All stainless steel parts tested before/after demagnetization
- All stainless steel parts will be demagnetized prior to integration
- Mechanisms have larger magnetic signature than PVA
- Eddy current damper has remarkably low emitted field

unit	magnetic moment after demag. (mAm^2)
eddy current damper	1.8
root hinge	5.2
panel hinge	1.3
hold-down & release unit	0.9
PVA panel (incl. 1 string failure)	2.8

Conclusions

- Solar powered JUICE and Europa Clipper missions to unprecedented environment of Jupiter's icy moons
- Similar environments and similar requirements imposed by instruments
- Existing technology used
  - Azur 3G28 solar cell
  - Airbus ARA Mk4 panel substrate technology
- Test program successfully completed to demonstrate technology for JUICE environment
- Structural verification Europa Clipper panels ongoing

Acknowledgments

Europa Clipper

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JUICE

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Thank you