HIGHLY EFFICIENT MEMBRANE-BASED PHOTOVOLTAIC ARRAY FOR SOLAR SAILING MISSIONS

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DLR

Aim of the DEAR Activity

Aim to develop a flexible membrane-based solar array which

- generates 100W power end-of-life
- can be stowed in and deployed out of a 1U CubeSat volume.

Funding:

under ESA contract 4000133890/21/NL/MM/ra

in the ARTES advanced technology programme

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ENABLING TECHNOLOGIES

Content

- Requirements
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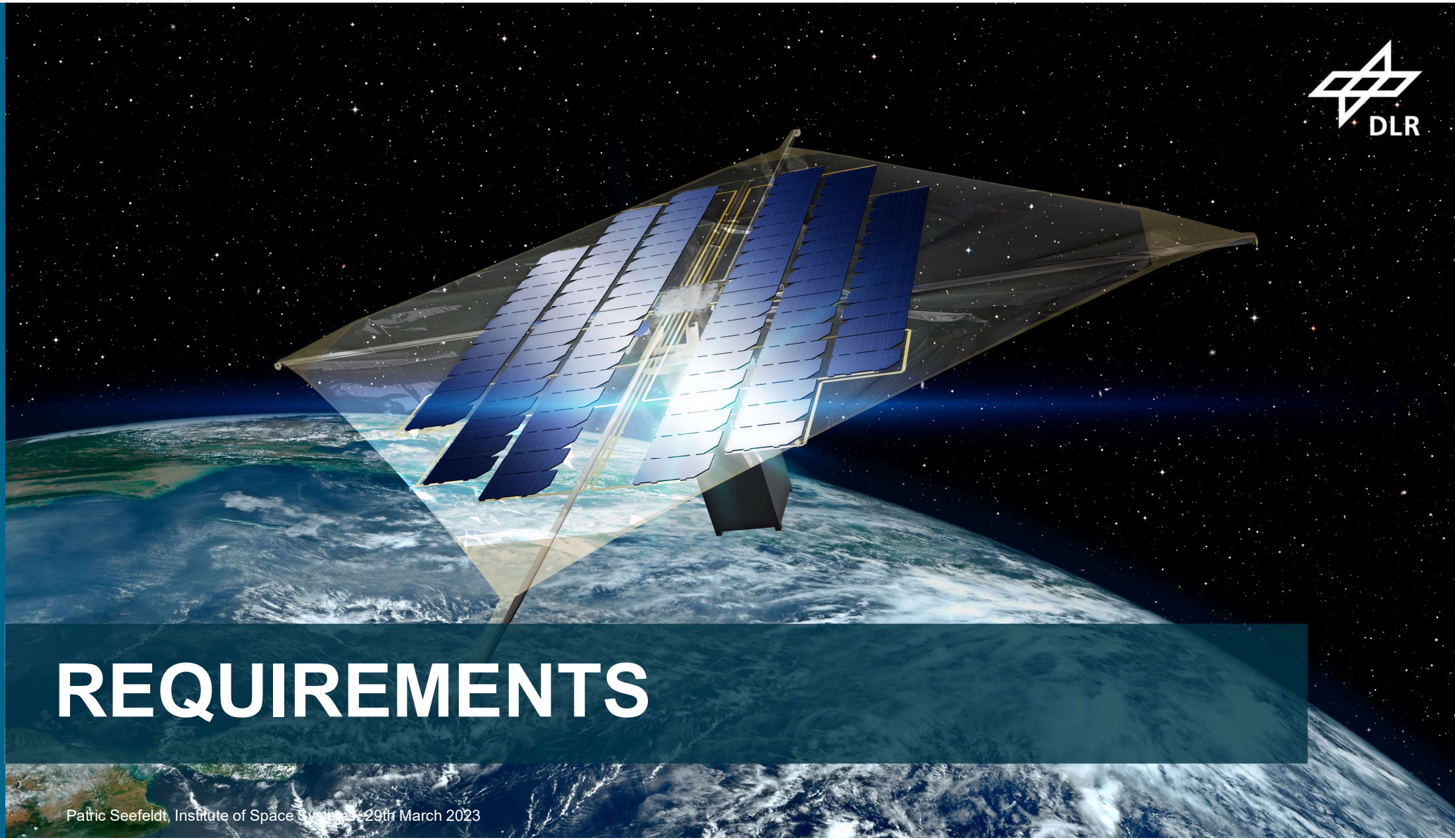
  - Orbit decay and atomic oxygen fluence
  - Radiation
  - Thermal
- Design and sizing
  - Electrical sizing
  - Magnetic compensation
- Membrane (breadboard)
  - Manufacturing
  - Stowing and deployment
- Outlook



REQUIREMENTS

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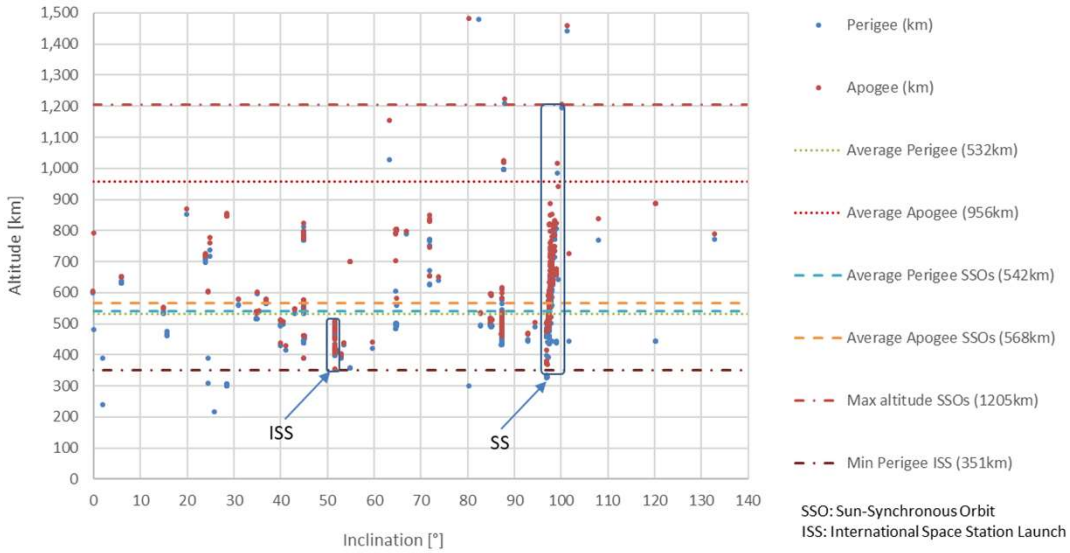
Top Level Requirements

- The solar array shall generate 100W at EOL.
- Operational Lifetime (in LEO)
  - Ground: <2 years
  - In-orbit stowed: <6 months
  - In-orbit deployed: <5 years
- The solar array shall operate with a bus voltage compatible with CubeSat platforms.
- The mass shall be lower than 2000g.
- The dimensions shall be such that the solar array can fit inside a 1U volume.
- The device shall be compatible with CubeSat structures.
- The device shall be scalable.
- The device shall be compliant with the debris generation requirements for space debris mitigation.

Mission Definition and Analyses for derived Requirements

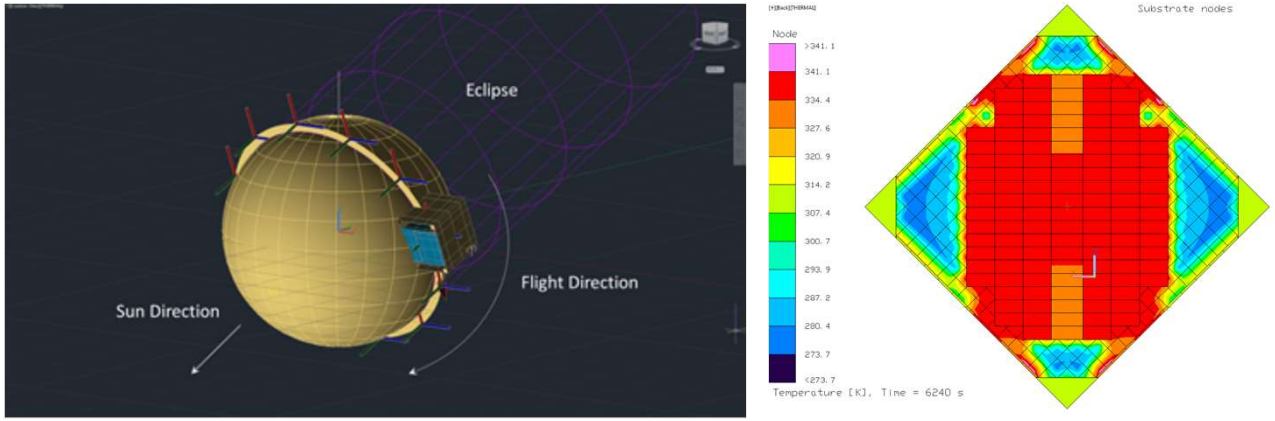
Radiation/ATOX:

- 2 clusters of launches (SSO and ISS) from USC satellite database identified
- Assumption:
  - Radition doses for high altitude orbits of constant altitude
  - ATOX doses for low altitude orbits including orbit decay



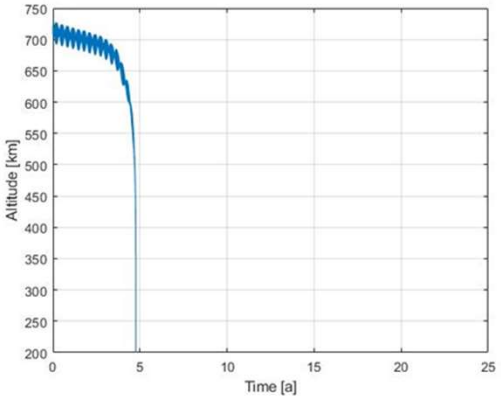
Thermal:

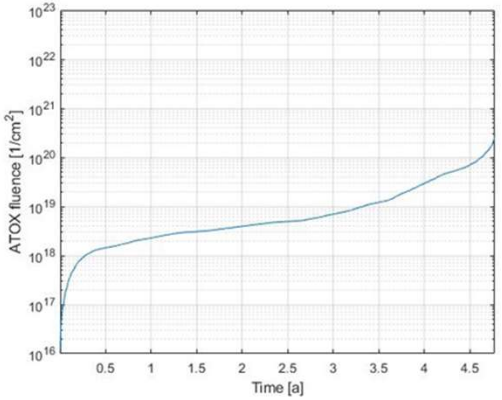
- Hot and cold worst case orbital conditions for stowed and deployed configuration
- Non-op temperature range -30°C ≤ T ≤ 70°C can be achieved
- Deployed membrane temperature range -92°C ≤ T ≤ 71°C

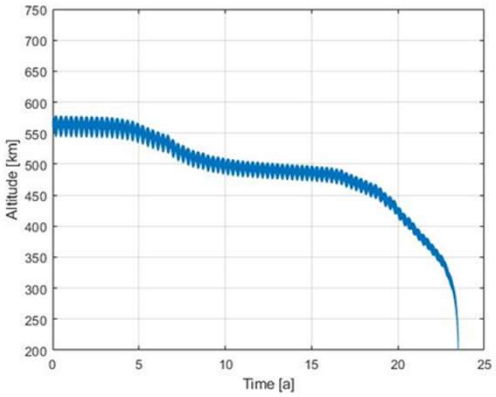


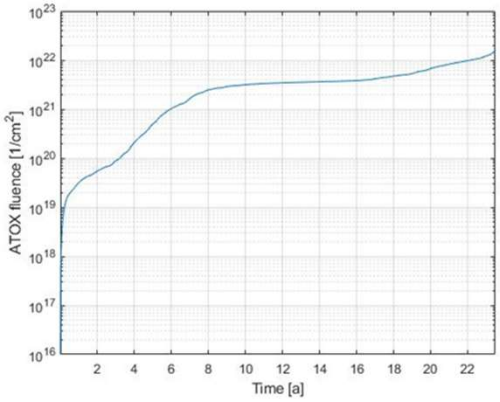
Orbit decay and atomic oxygen fluence

- ATOX fluence can vary at least two order of magnitudes
- Mission life time 5 years, fluence: $\approx 3 \cdot 10^{20}\ \mathrm{AO/cm^2}$
  - For design considerations we use as minimum fluence $10^{21}\mathrm{AO/cm^2}$
- For longer missions it can be in the order of $10^{22}\mathrm{AO/cm^2}$

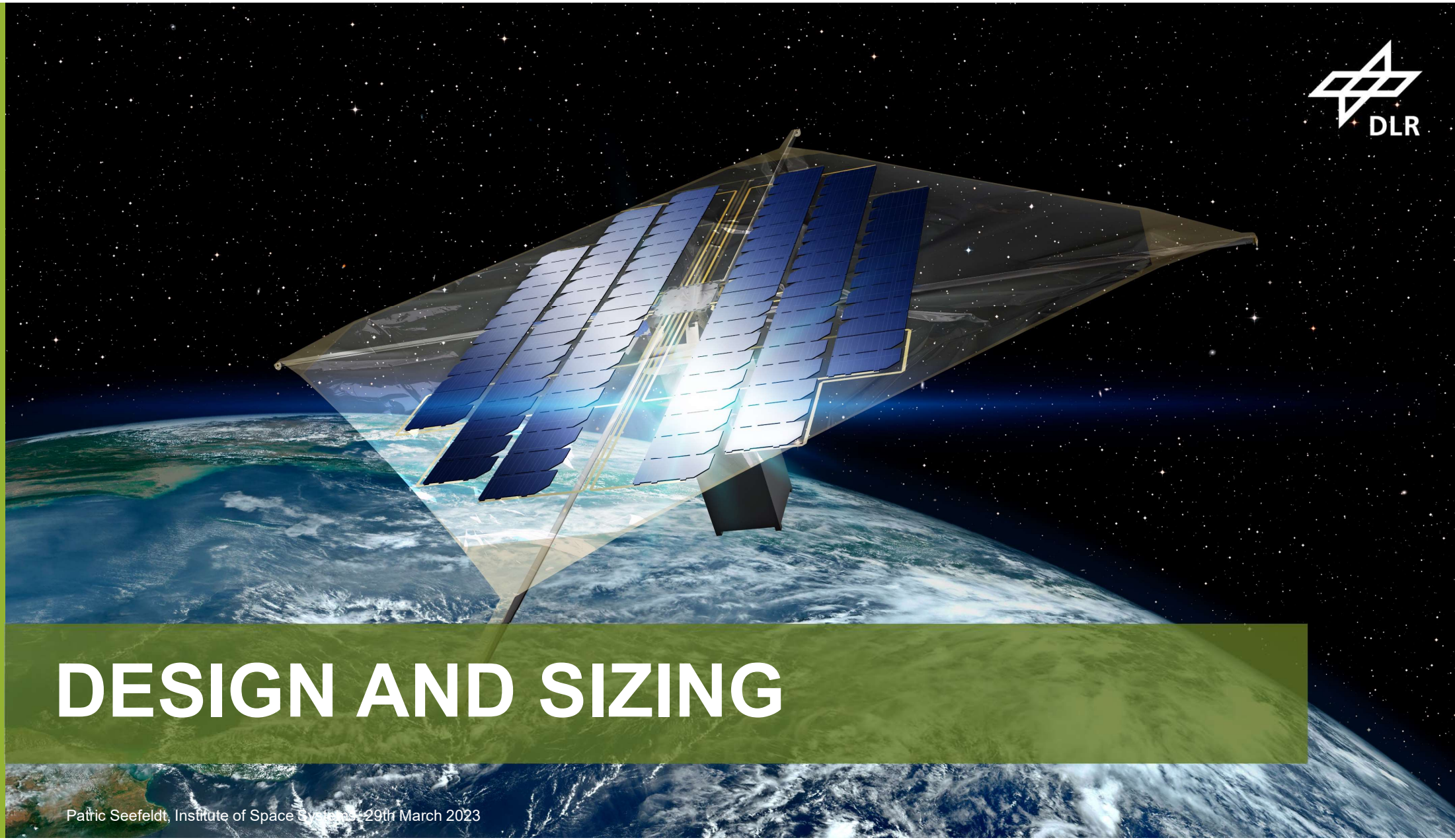








Mission Scenario (Initial Altitude)	Satellite Weight [kg]	ATOX Fluence After 5 years [$\mathrm{cm^{-2}}$]	Years at re-entry (200km)	ATOX Fluence at re-entry (or after 25 years) [$\mathrm{cm^{-2}}$]
SSO (700 km)	3	$(\approx 3 \cdot 10^{20})$	4.77	$2.91 \cdot 10^{20}$
SSO (560 km)	200	$5 \cdot 10^{20}$	23.5	$1.62 \cdot 10^{22}$



DESIGN AND SIZING

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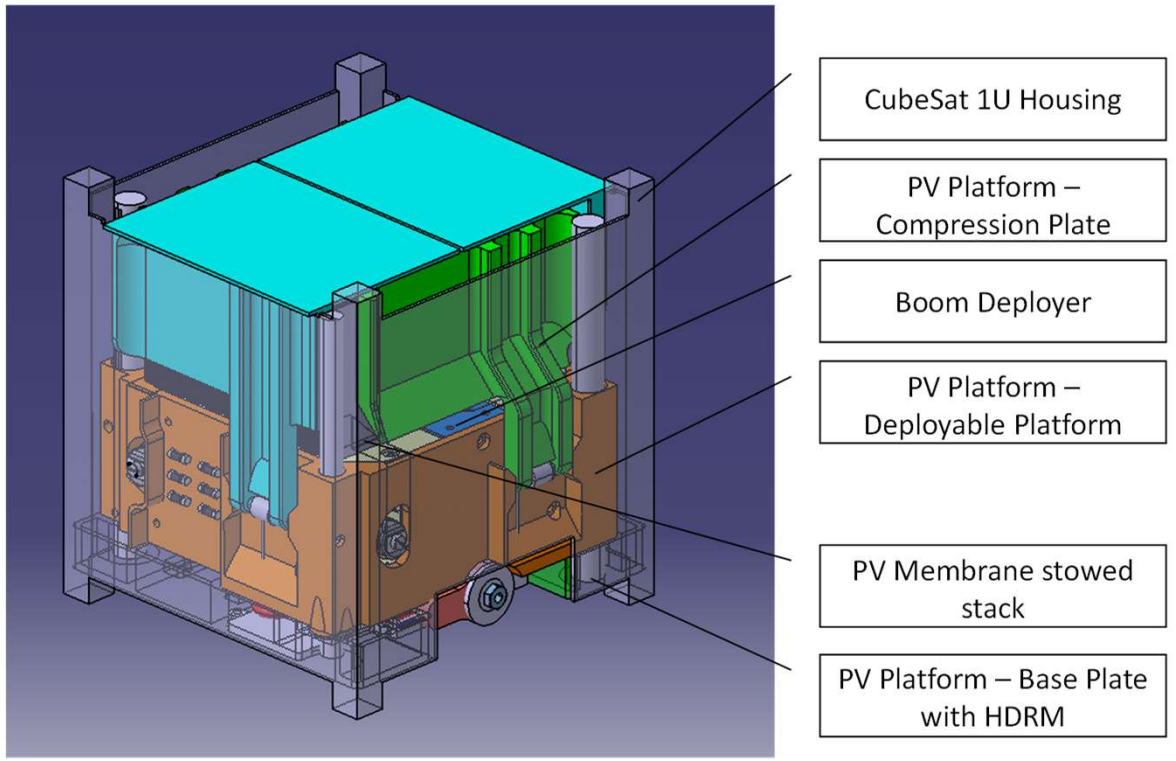
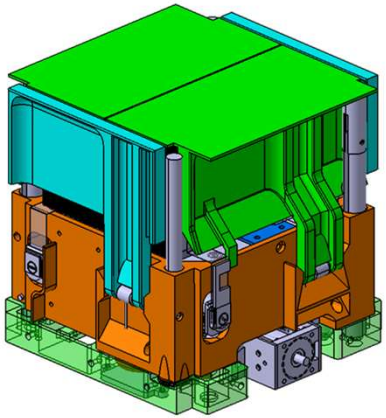
Overall System Concept

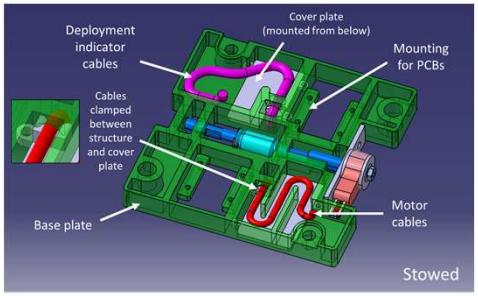
- CubeSat housing which provides the interface to the base plate and gives support to the compression plates in stowed configuration
- Base plate which is fixed to the CubeSat structure to hold and release the deployable PV platform
- Deployable PV platform to lift boom deployer and folded PV blanket out of the 1U volume
- Deployable compression plates which firmly fix the the folded PV blanket as protection against mechanical loads
- Two-dimensionally folded PV blanket membrane equipped with SCAs and harness
- Boom deployer to deploy the PV blanket in two directions independently

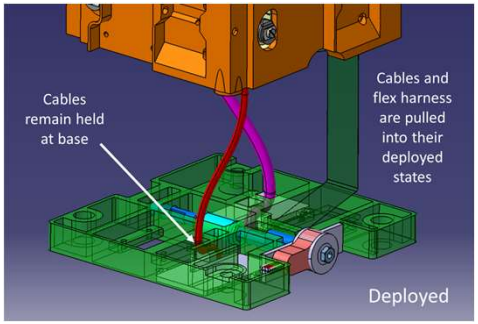


Base Plate and PV Platform

- Base plate
  - Rigidly connected to CubeSat structure
  - Contains the HDRM to release the PV platform
  - Contains guiding rods with springs for PV platform deployment
  - Houses the system and PV harness in stowed configuration
- PV Platform contains
  - compression plates
    - To firmly fix the stowed PV blanket against mechanical loads
    - To secure the PV blanket against relative motion between SCAs and CubeSat housing
    - Blocked by CubeSat structure in stowed configuration
  - Boom deployer for PV blanket deployment
  - HDRM counter part for PV platform release
  - Volume for PV harness including blocking diodes

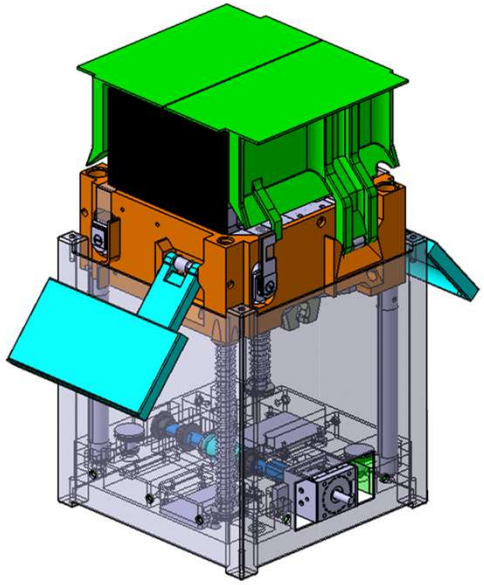


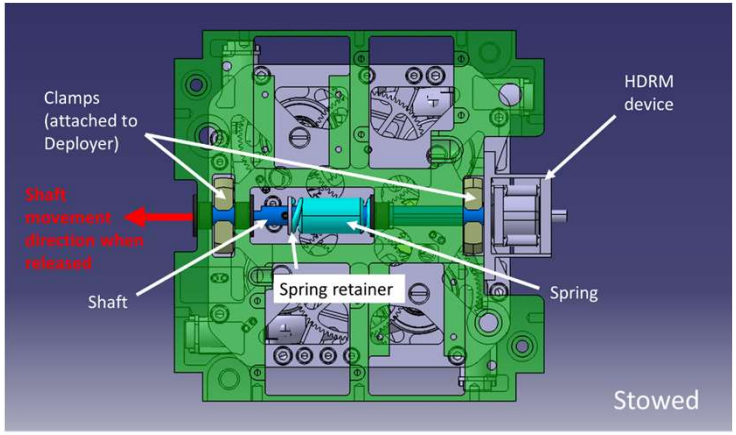


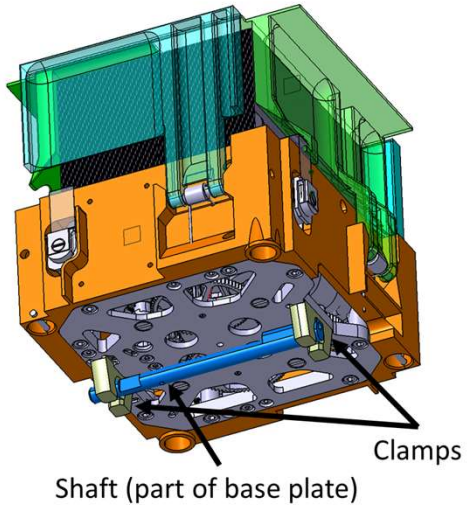


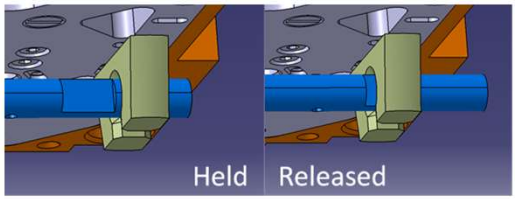
PV Platform Release Mechanism with HDRM CREAM

- Translational movable rod with different cross section (round/flat)
- Rod preloaded by spiral spring
- Rod held and released with CREAM HDRM (low-shock, self-resetting)
- Upon release round shape of shaft moves out of clamp and flat shape moves in clamp releasing the PV platform



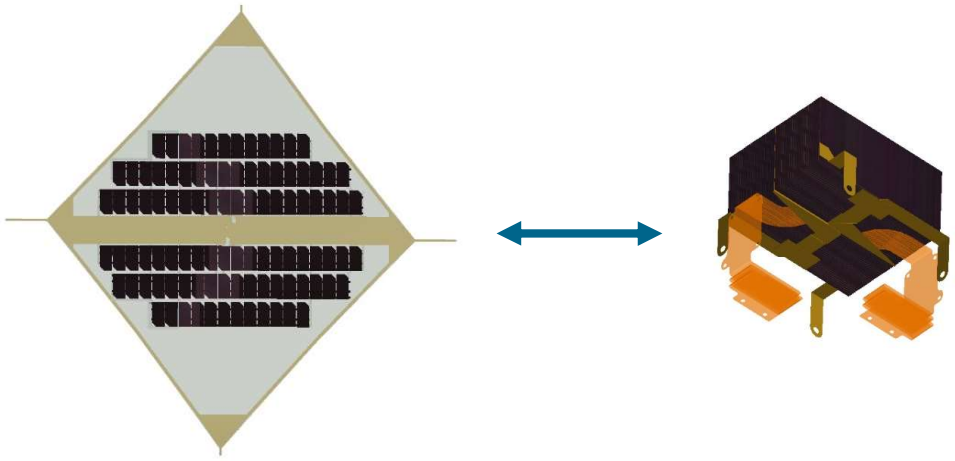


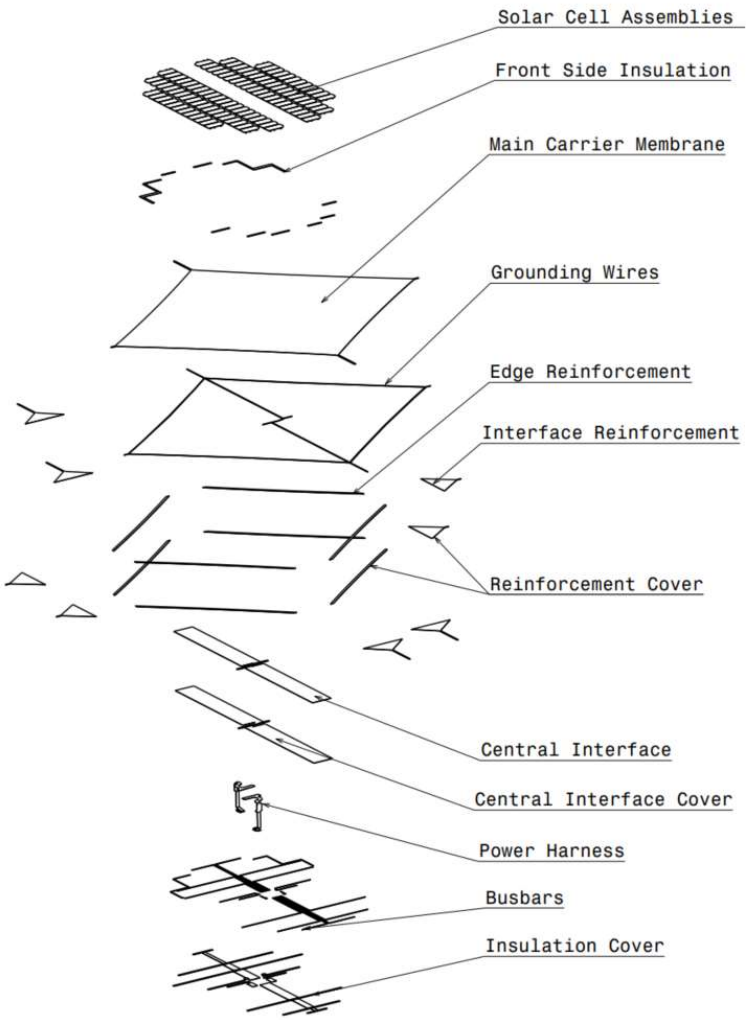




The DEAR blanket concept

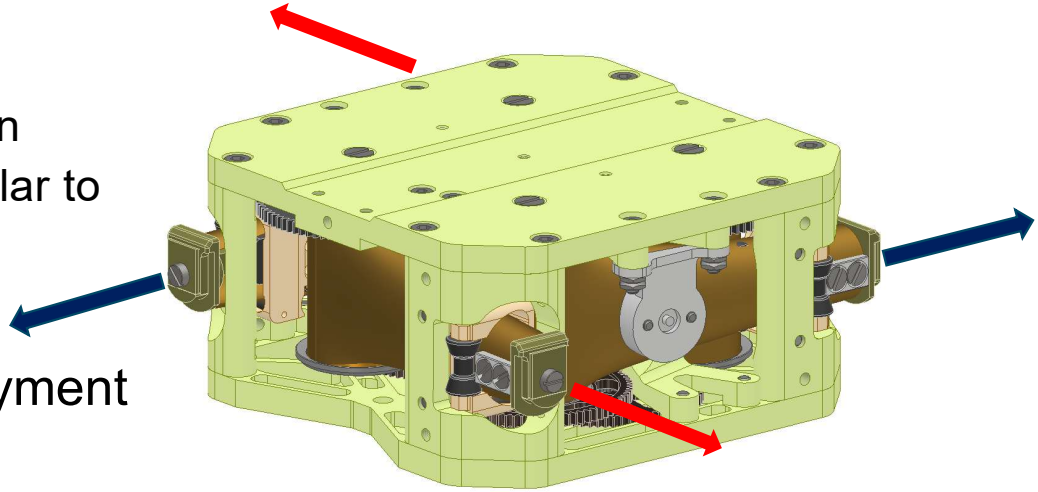
- A foldable 100W array (EOL)
- Fits into 1U of a CubeSat (including deployer)
- 700 g, <1 m^2
- FEP membrane (25µm) - stowage efforts, mass, volume, ATOX resistance
- 100 3G30A Solar Cell Assemblies
- Kovar membrane harness

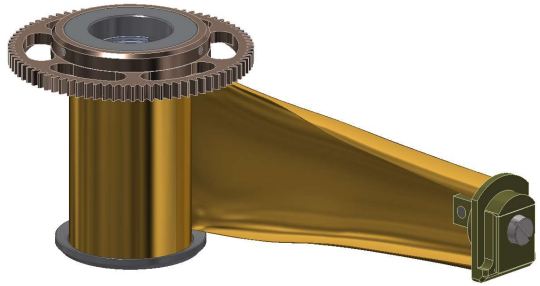




Boom Deployer

- Deploys CuBe ciruclar tape spring booms
  - Two booms simultaneously in opposite direction
  - Another two booms simultaneously perpendicular to the first direction
- One motor per deployment direction
- Gives start-of-deployment and end-of-deployment feedback
- Tensions the PV blanket to the desired pretension force
- Volume: 80mm x 80mm x 40mm
- Mass: 290gr
- Boom length: 700mm





MANUFACTURING / TESTING

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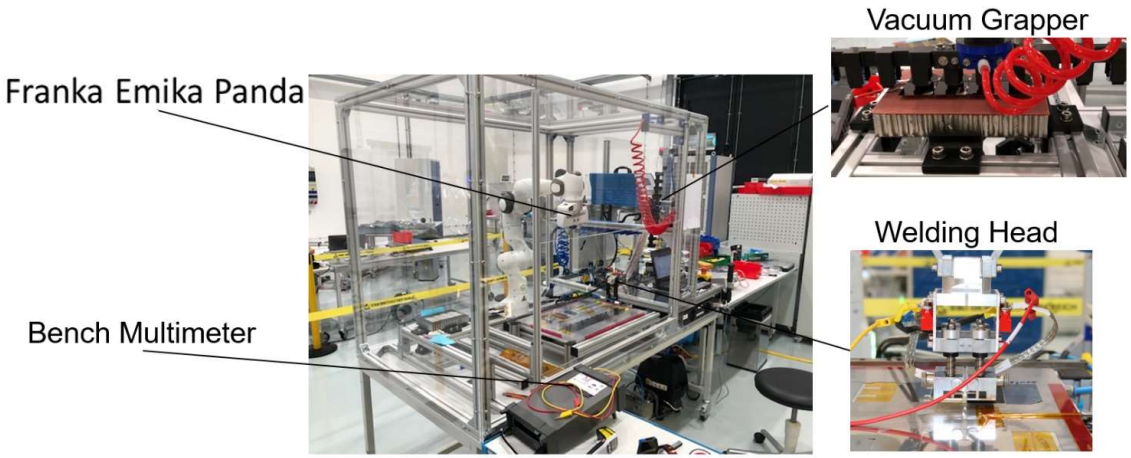
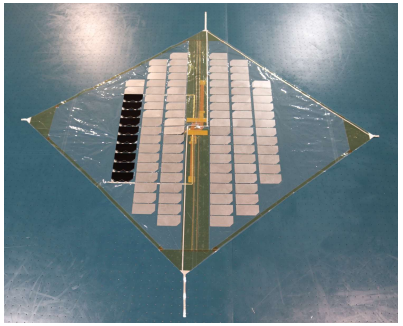
Manufacturing

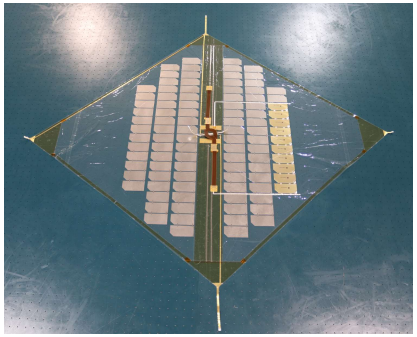
- The manufacturing process, in particular the electrical interconnection of the solar cells, is partially automated using a Franka Emika Panda robot equipped with various tools for spot welding and handling the interconnected strings.

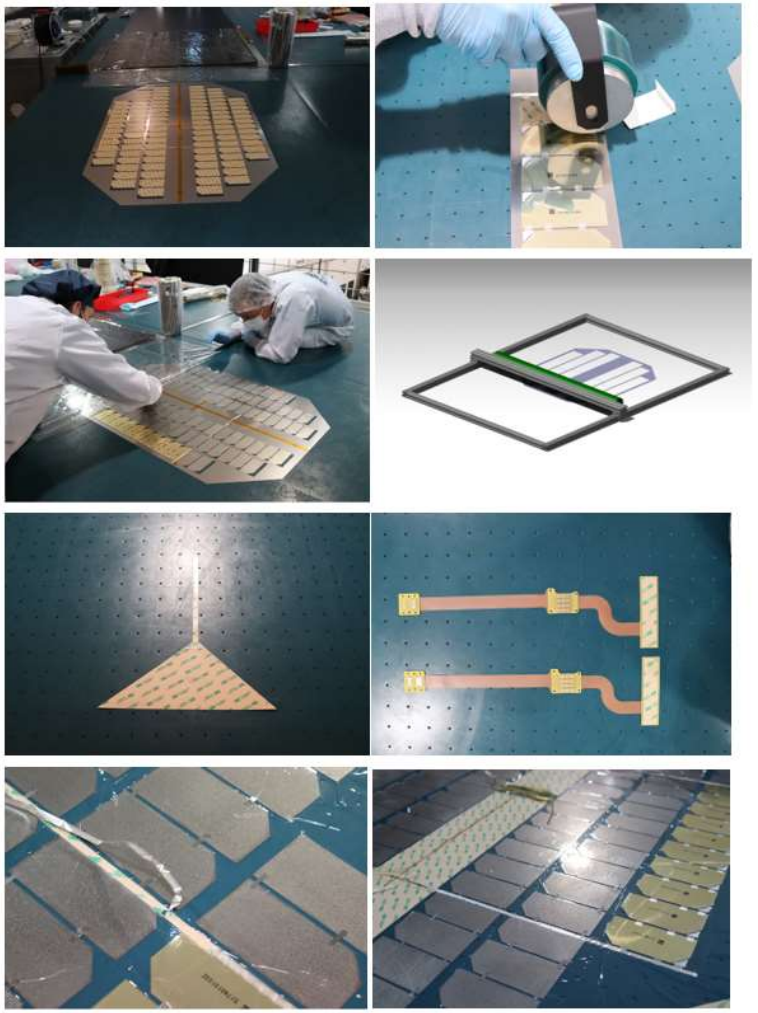


Manufacturing

- Interconnected strings are arranged using a stainless steel template .
- Acrylic transfer adhesive is applied with rolers.
- Components such as interfaces, harness, reinforcements are integrated.

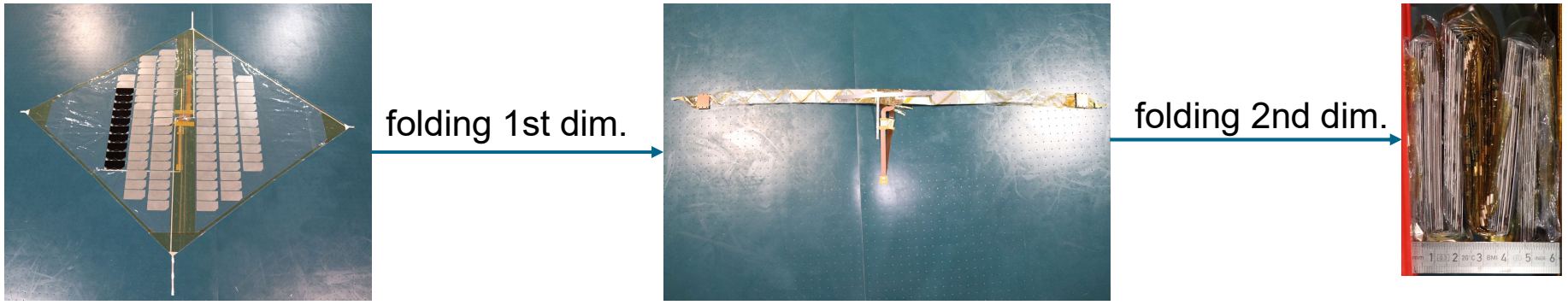






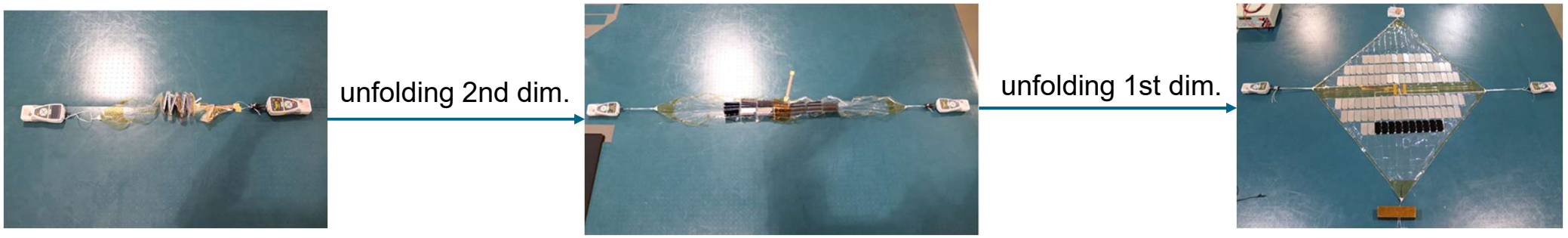
Blanket breadboard

- 1st zig-zag folding perpendicular to the main harness
- 2nd zig-zag folding of the folded strip such that all cells are lying on top of each other



Manual unfolding and functional check

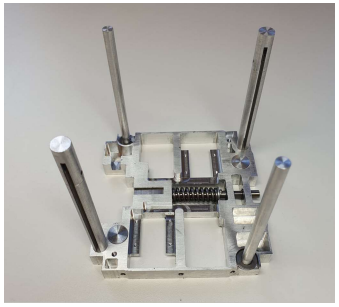
- First manual tests with the blanked were carried out (handling and manual stowing and deployment)
- Deployment forces decisively lower then boom maximum loading during boom deployment

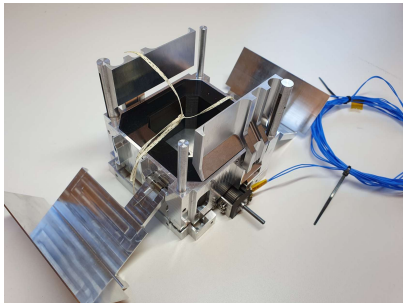
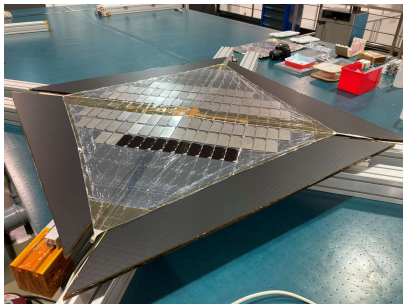
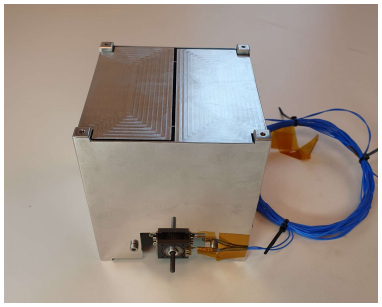


System Breadboard Hardware

Mechanical BB consisting of

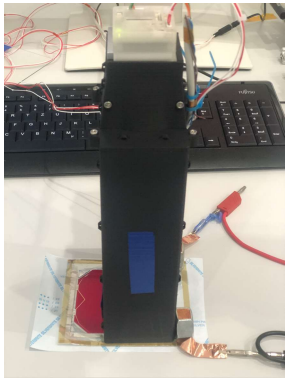
- Base plate with CREAM HDRM and guiding rods
- Boom deployer
- PV Platform with compression plates
- PV blanket breadboard
- CubeSat housing

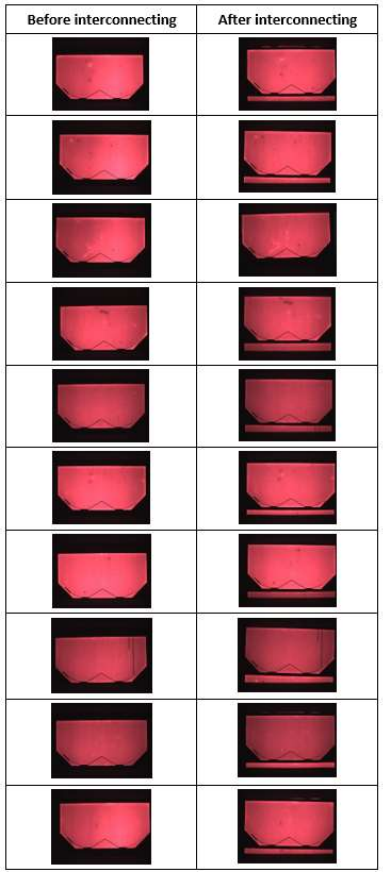


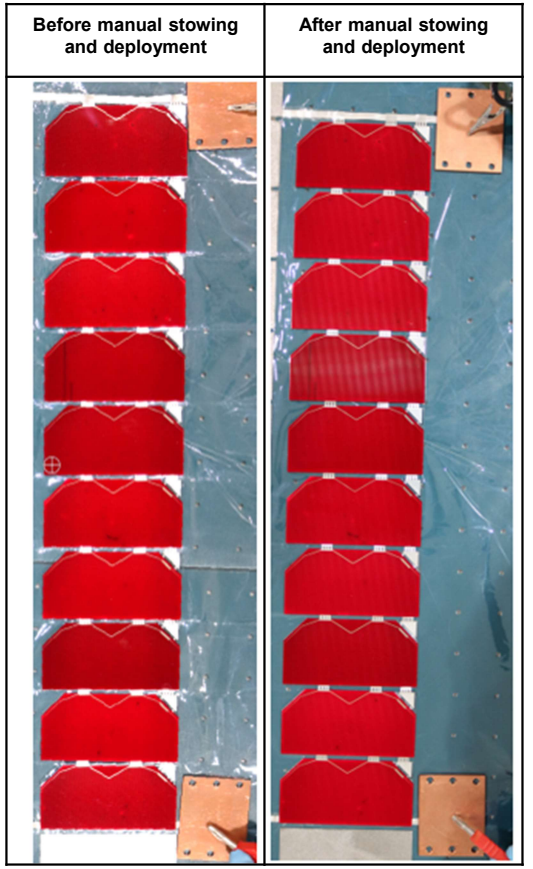




Manual unfolding and functional check

- Quality control and functional checks are made using electroluminescence
- A cover with a camera can also be used for this purpose in order to create comparability of the images (same illumination and camera settings)

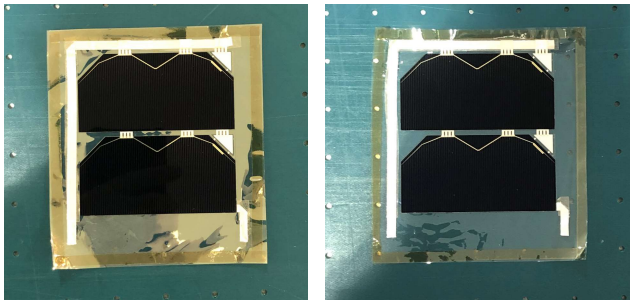


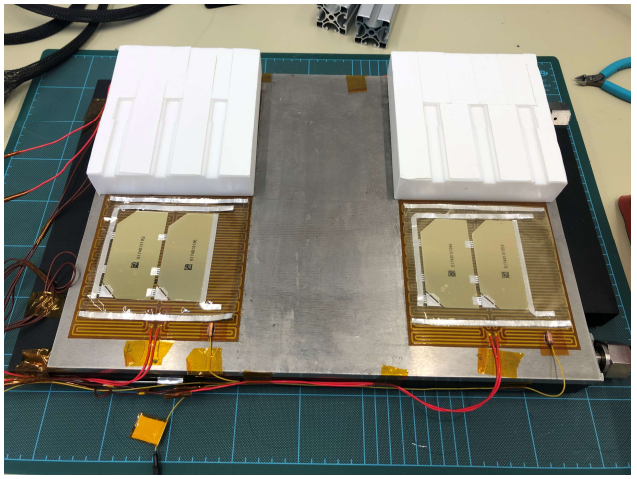




Electrical breadboard

- Two electrical breadboards were manufactured (each with a two-cell string)
- These breadboards are currently subject of a thermal-vacuum cycling test
- The breadboards will also be included in first vibration testing

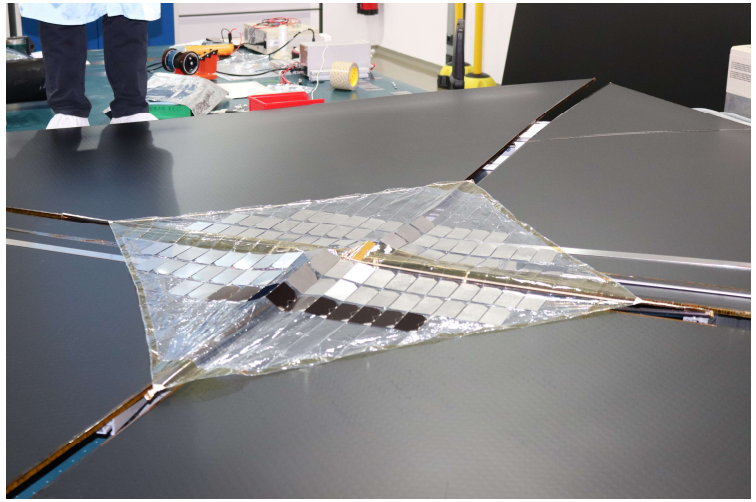


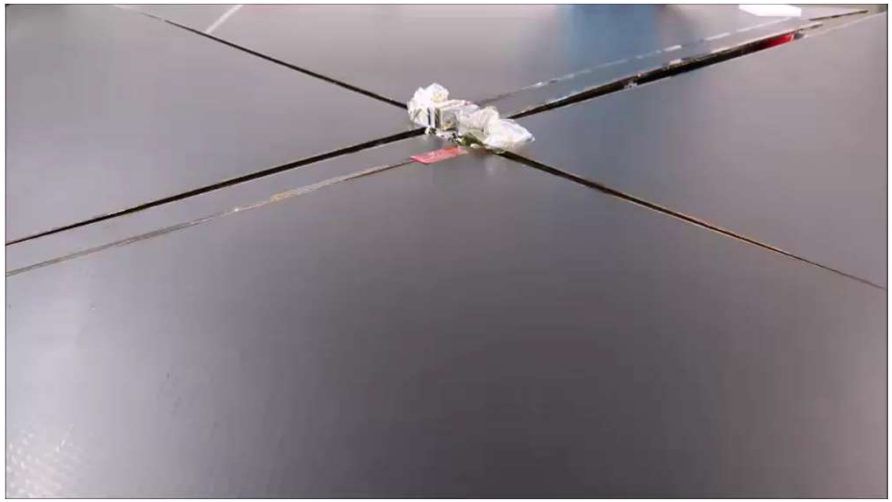


System Breadboard Testing

Testing of

- Ambient deployment
- Vibrational loads
- Thermal loads in vacuum
- Release and deployment in thermal environment

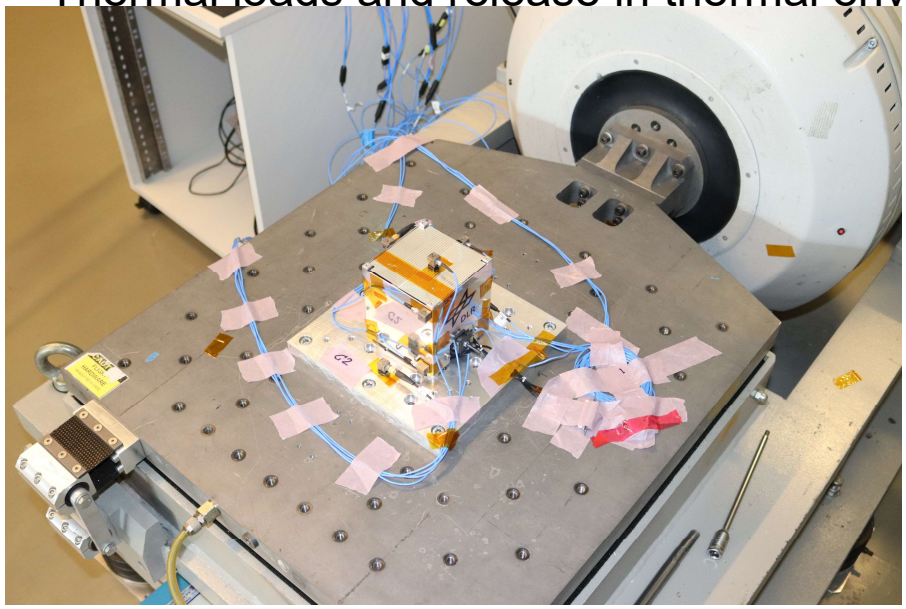


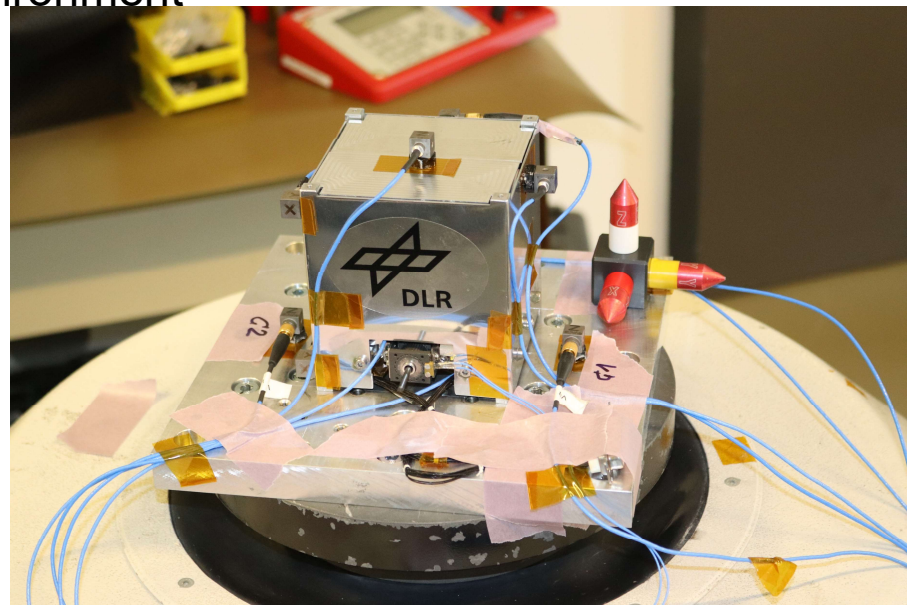


System Breadboard Testing

Testing of

- Ambient deployment
- Vibrational loads
- Thermal loads and release in thermal environment





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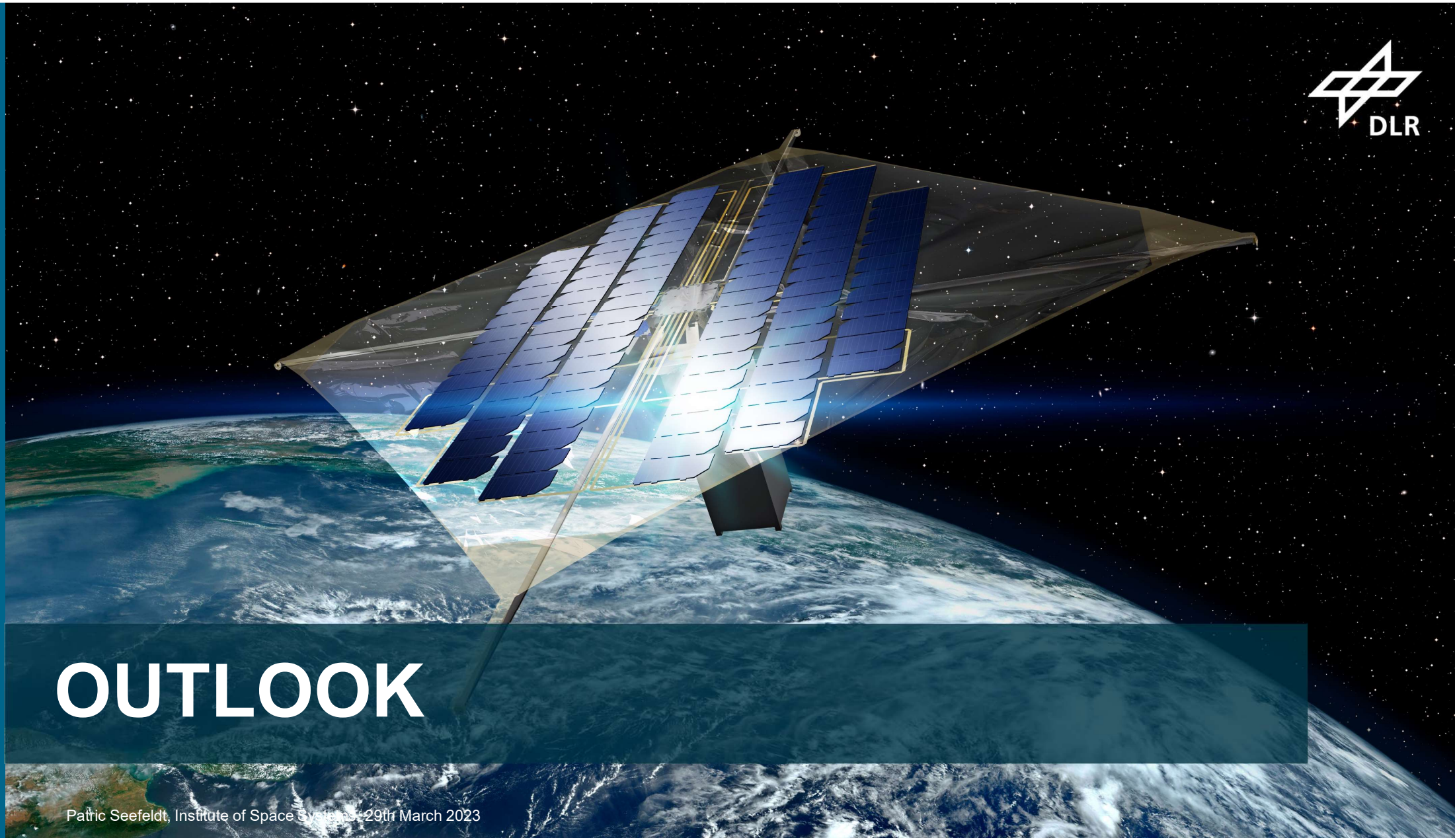

OUTLOOK

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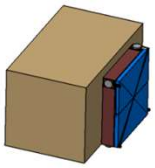
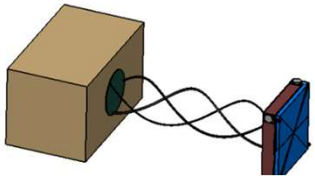
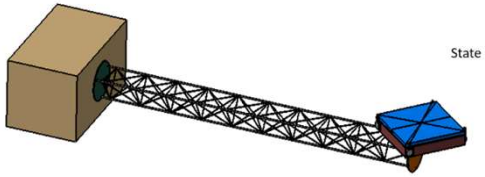
Scaling to power Sails



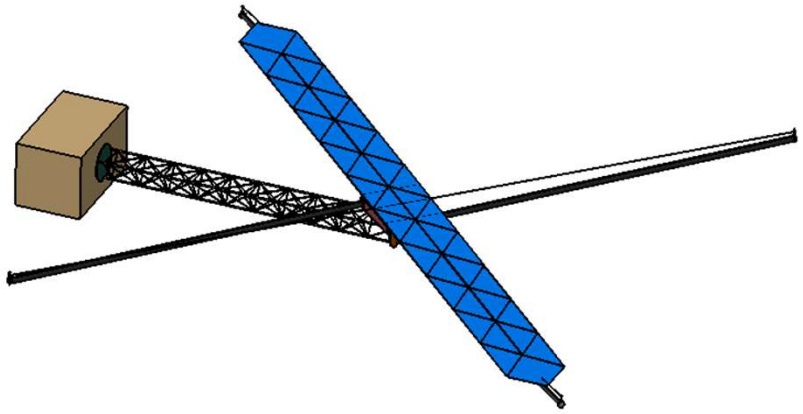
State 1) Coilable-Boom stored inside the deployable package

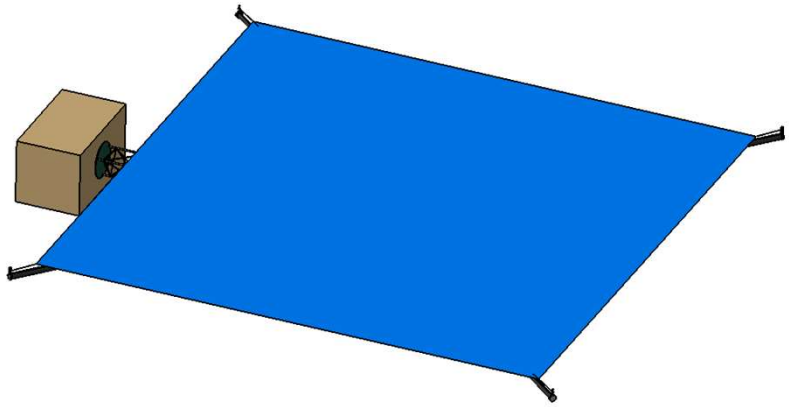


State 2) Coilable-Boom deployed half way (Image not fully accurate)



State 3) Package tilted 90° (final deployment position)





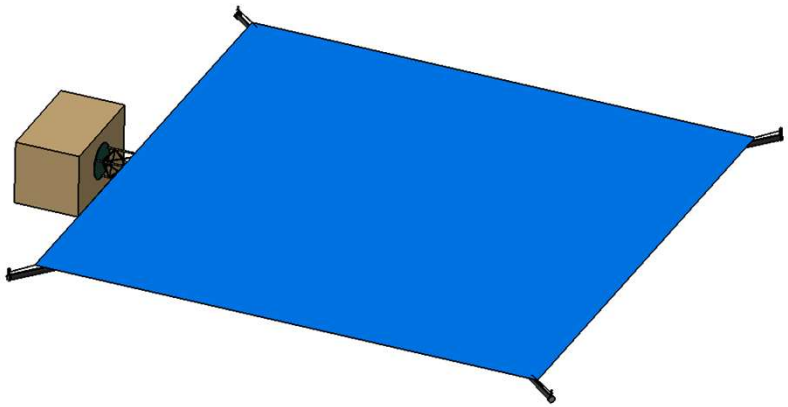
Scaling to power Sails

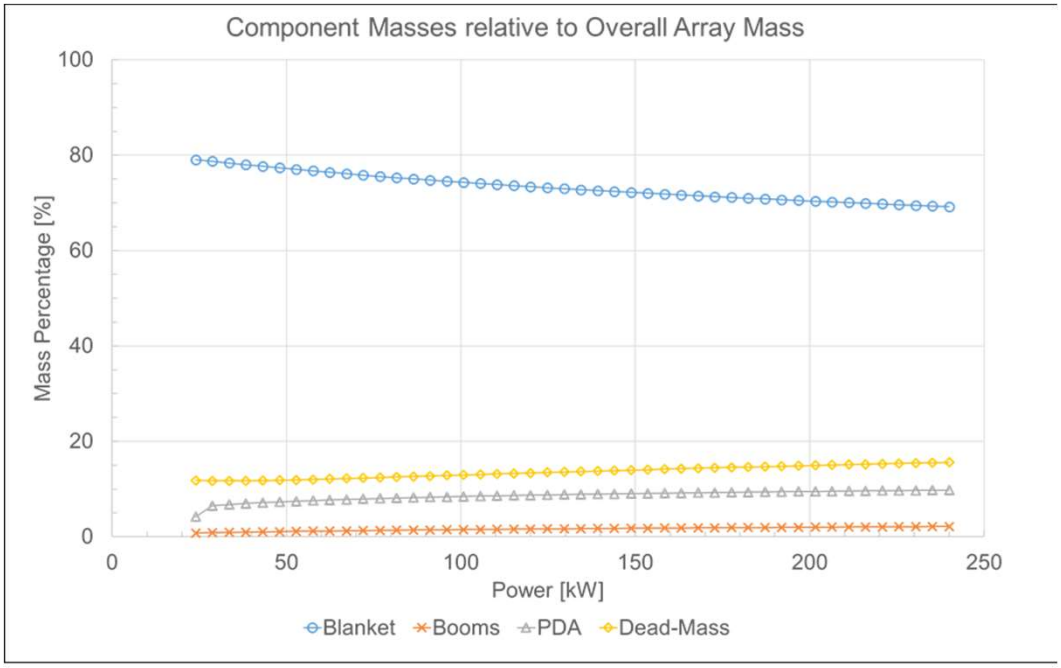
Stowage volume

- 300 kW (2x 150 kW wings): 63 kW/m³
  - 150 kW wing: 2.2 m x 2.2 x 0.56 m

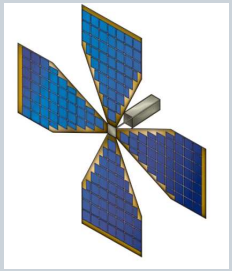
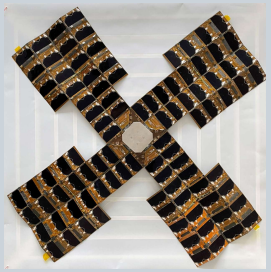
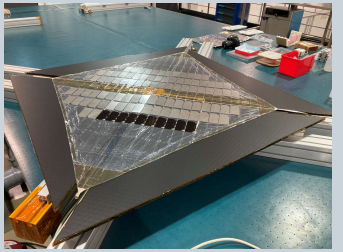
Mass

- 300 kW (2x 150 kW wings): 127 W/kg
- 150 kW/wing:
  - 72.1 % blanket weight (861kg)
  - Blanket 1.2 kg/m²
  - Overall Area 750m²
  - Overall Mass 1.2t (PDA 71kg)



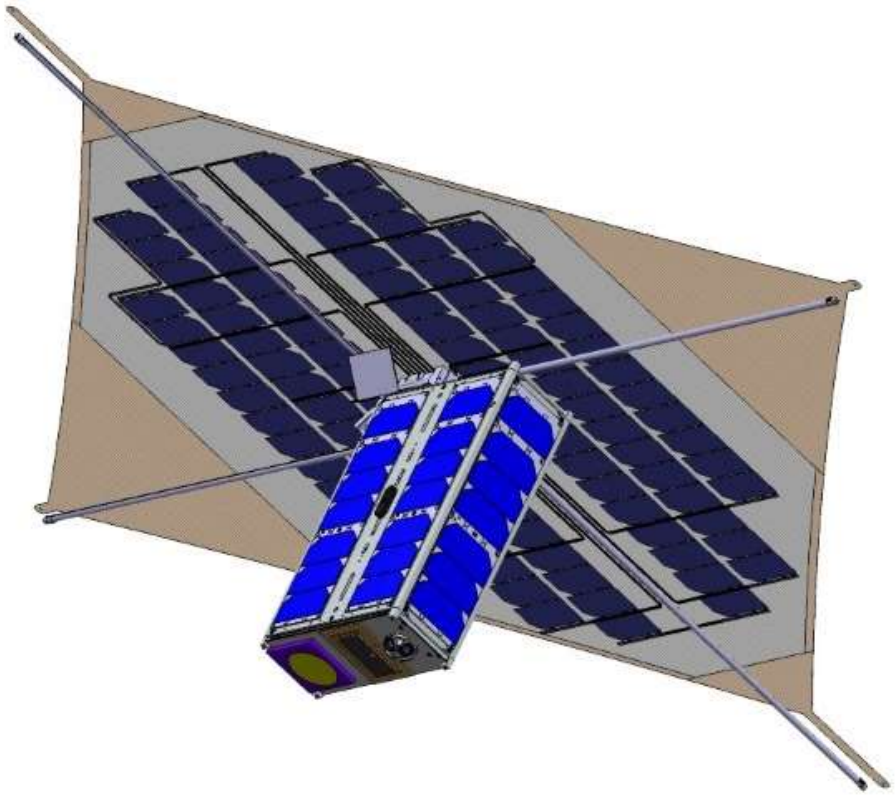


Comparison to other Solar Array Systems

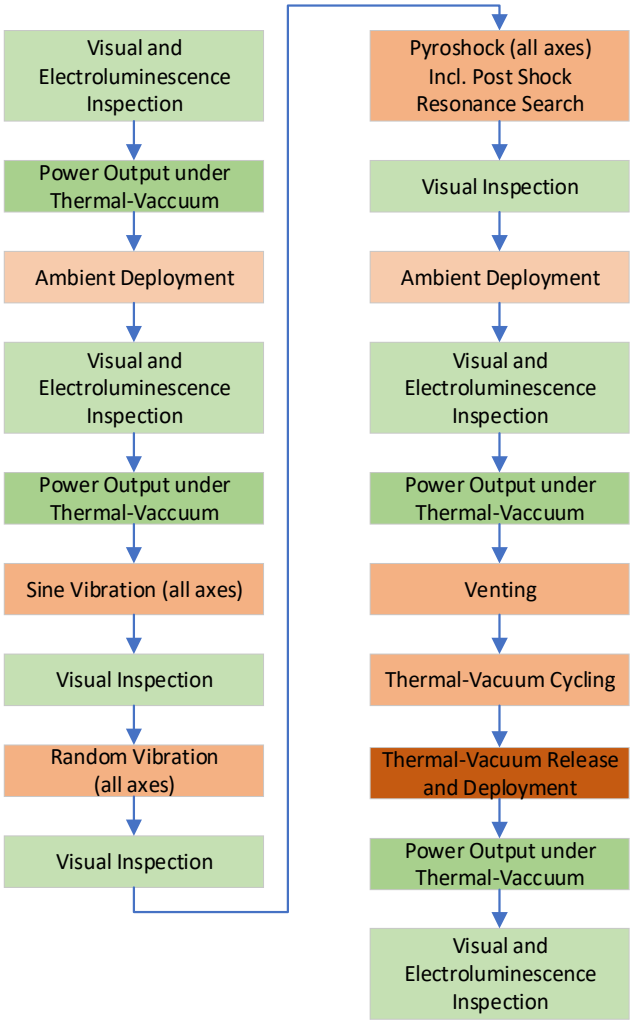
Parameter	Lisa-T (pointed)	PowerCube	DEAR
			
Array design	Flexible membrane with tape springs and SMA support	Dual-matrix composite substrate	Membrane with supporting booms
Solar Cell Type	triple junction thin-film solar cell	3G30A triple-junction GaAs	3G30A triple-junction GaAs
Mass [kg]	-	< 2	1.7
Power [W]	> 200 (BoL)	100 (EoL)	100 (EoL)
Volume Specific Power [kW/m³]	> 200 (BoL)	100 (EoL)	100 (EoL)
Mass Specific Power [W/kg]	> 250 (BoL)	> 50 (EoL)	60 (EoL)

Outlook

- Critical Design Review end of June 2023
- Test Campaign Q4/2023 with EM fully equipped with 100 SCAs
- In-orbit Demonstration on a DLR technology demonstration mission, a 6U CubeSat on second launch of ISAR Aerospace Q2/2024



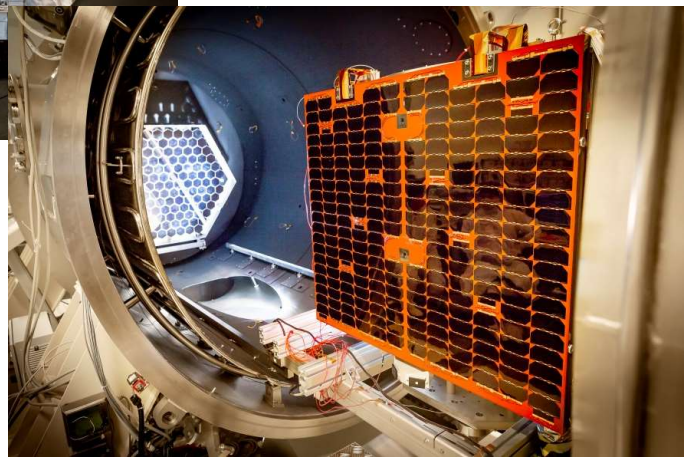
Engineering Model Integration and Testing



Mechanical Test Laboratory for Vibration and Pyroshock Testing

TV-Test Lab for TV Deployment

and Power Output measurements



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Thanks to our ESA responsible technical officer Evelyne Simon and her colleagues Paul Hodgetts and Barnaby Osborne.

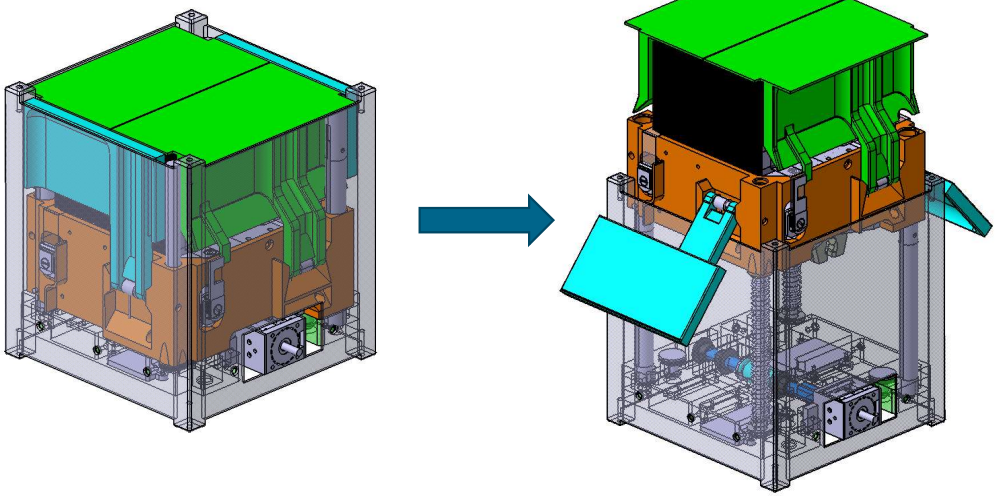
Further we thank the German ARTES delegation, in particular David Futterer, for the support of this activity.

Thank you for your attention!

Impressum

Thema:	The DEAR 100W Deployable Solar Array for SmallSats
Datum:	29.03.2023
Autor:	Tom Sproewitz
Institut:	Institute of Space Systems
Bildcredits:	all pictures „DLR (CC BY-NC-ND 3.0)“

Overall System Deployment Concept

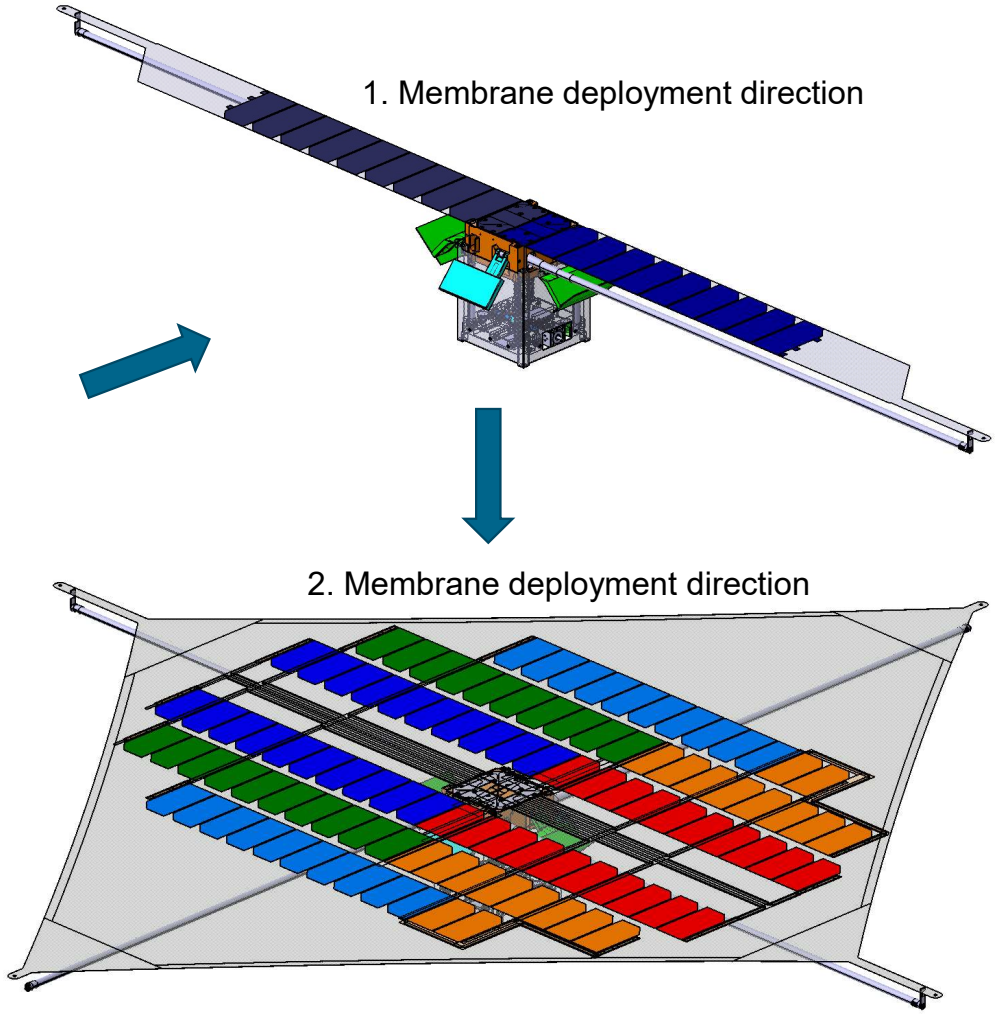


Stowed configuration

PV platform released

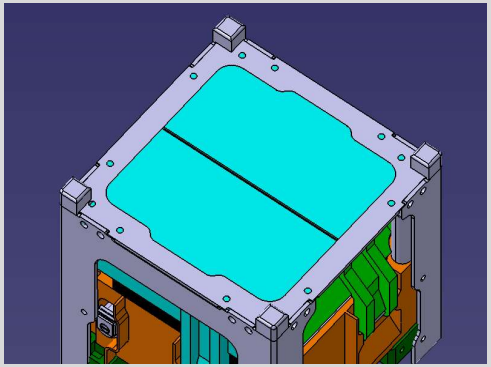
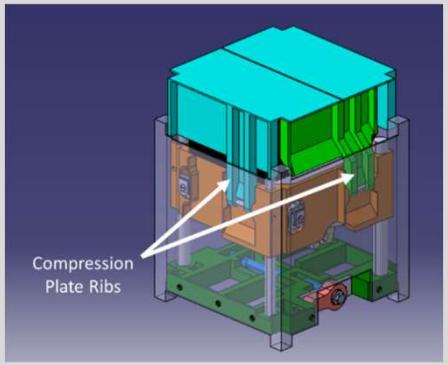
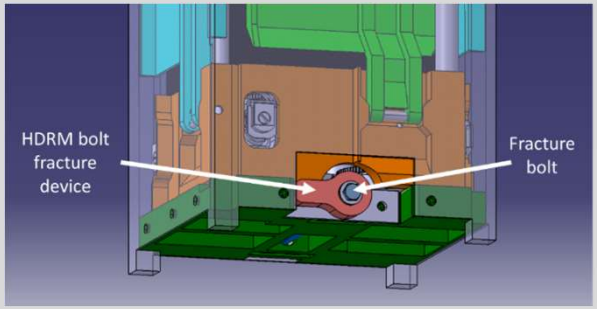
1. Membrane deployment direction

2. Membrane deployment direction



CubeSat Structure Survey

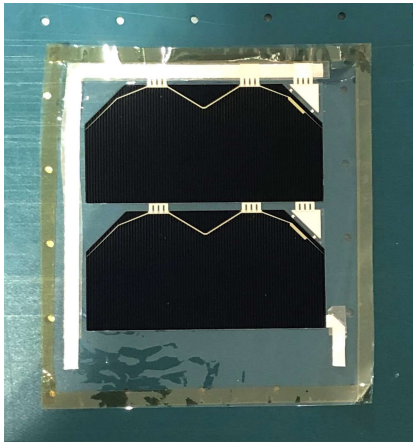
- DEAR is designed to fit into and to interface with a „generic“ 1U CubeSat volume
- A great variety of commercially available CubeSat structures exists which are CDS conform qualified for use
- Survey to asses compatibility of commercially available structures with DEAR
- Critical Interfaces that were considered by virtual fit checks are:

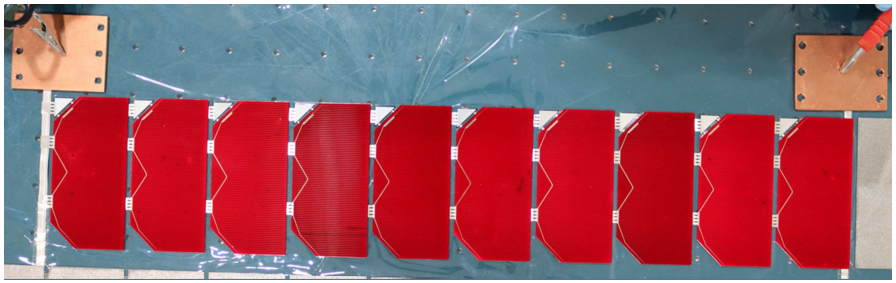
Structure top opening	Compression plate surface	HDRM access
		

- Results of virtual fit check
  - Main problem was size of top opening
  - Design of side walls not always advantageous for compression plate support
  - HDRM access primarily ok

Subsystem Breadboard Hardware and Testing

- Electrical BB:
  - Electrical contacting
  - Thermal cycling testing
  - Vibration testing
- PV blanket breadboard with 1 string (10 SCAs) funktional PV and 90 structural SCA dummies
  - Integration testing with tools
  - Stowage tests
  - Deployment force determination
  - Health status testing by electroluminescence

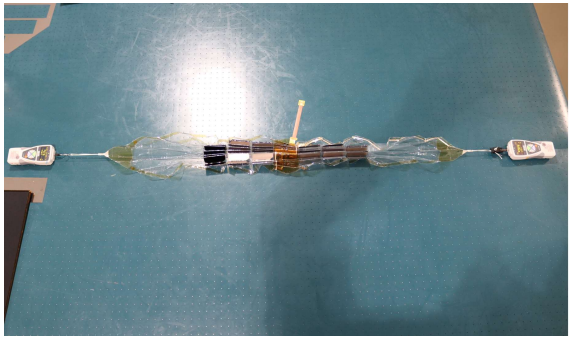




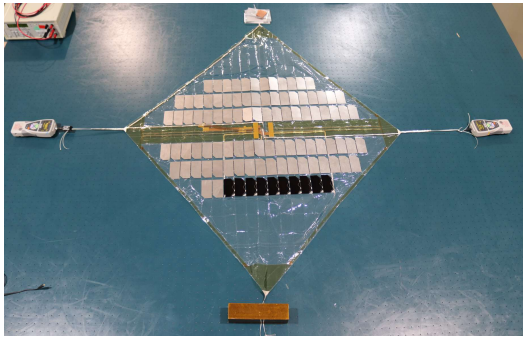
Stowed compressed

Stowed free

First direction deployment



Second direction deployment



PV Blanket

- FEP membrane of suitable thickness (25µm) wrt. stowage efforts, mass, volume but also ATOX resistance
- 100 3G30A Solar Cell Assemblies
- Kovar on-membrane harness
- flexPCB System harness with PCB boards for blocking diodes and connectors (between membrane and connector to PCDU)