Development of New Solar Array Concepts for Space Applications

DLR Institute of Space Systems
Mechanics and Thermal Systems

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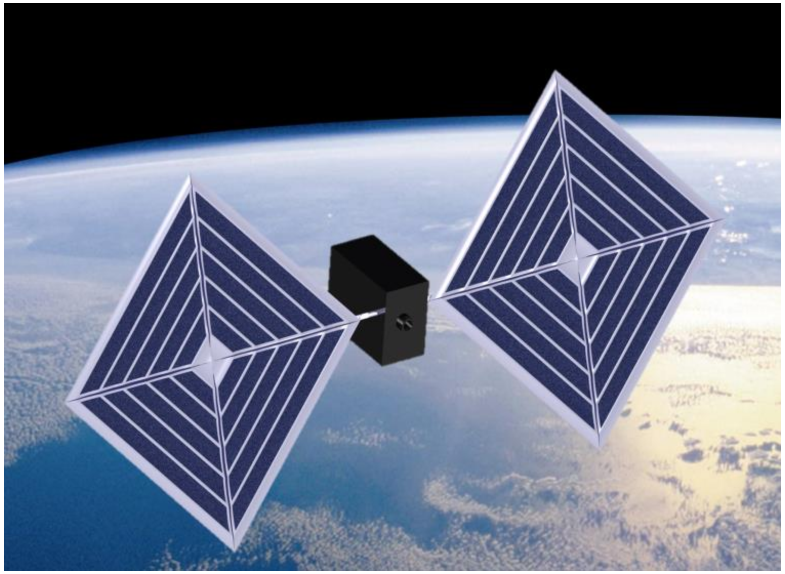
Introduction

- Power demands of space missions are increasing (e.g. electric propulsion)
- The increase of efficiency of the solar cells itself is limited
- Conventional solar arrays are composed of stiff backing structures and brittle PV cells
- New approached use flexible solar array designs with new PV technologies (e.g. CIGS, thinned wafer)
  - ➢ Increase power/mass and power/volume ratios
- Technology shall be suitable to generate power in the order of a few 10^{th} of kWs

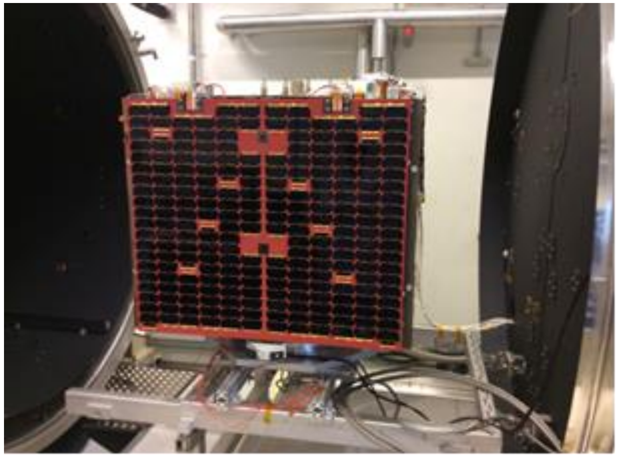


⇨ Not beyond solar cells, but what are we doing to get the most out of it for space applications?

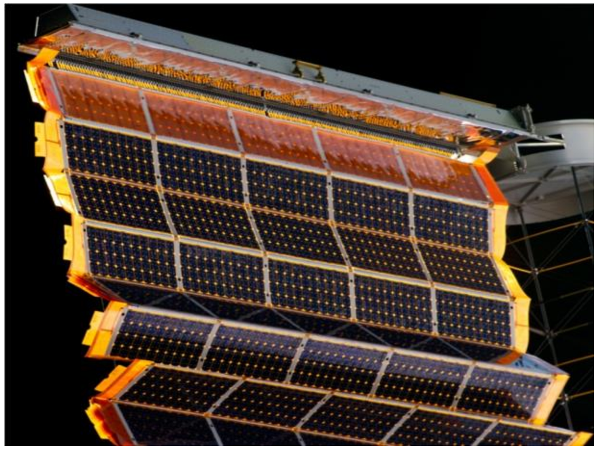
Solar Cell Technology

State of the Art

- Solar cells for space are dominated by GaAs-(III-V) multijunction technology (e.g. by Azur Space CESI, MicroLink)
  - 200 €/W, ≈30% efficiency (1W with 32cm^2), 100µm thickness (without coverglass), 1.6 g/W (without coverglass and backing structure)
  - >100µm cover glass, depending on radiation shielding requirements
  - Vulnerable to mechanical loads therefor used with backing structure (e.g. CFRP sandwich panels)
  - Body mounted or with hinges
- In the past, also for the ISS, Si-photovoltaic with around 15% efficiency was used (20% are possible)



DLR Eu:CROPIS Satellite

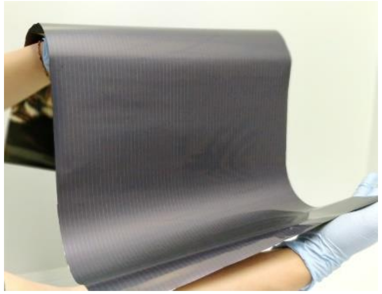


HAGUE, Lisa M., et al. Performance of International Space Station electric power system during station assembly. In: IECEC 96. Proceedings of the 31st Intersociety Energy Conversion Engineering Conference. IEEE, 1996. S. 154-159

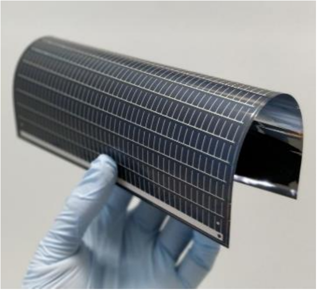
Solar Cell Technology

Flexible Solar Arrays

- Explore the potential of CIGS photovoltaic (DLR Project GoSolAr)
  - ➢ 20 €/W
  - ➢ ≈15% efficiency, in laboratory >20%
  - ➢ 30 µm thickness
  - ➢ 0.8-1,3 g/W (no cover glass and backing structure needed)
  - ➢ Truly flexible and not sensitive to mechanical loads
- Explore designs for which high efficient GaAs-photovoltaic is mounted on flexible carriers (ESA Project DEAR)
  - ➢ Use of thinned-wafer technology <50µm
  - ➢ Use of thin coverglasses (50µm)
  - ➢ Use coatings instead of coverglasses

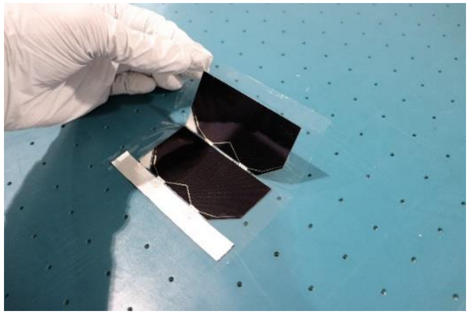


Flisom CIGS



Ascent Solar CIGS

CIGS photovoltaic on flexible carrier

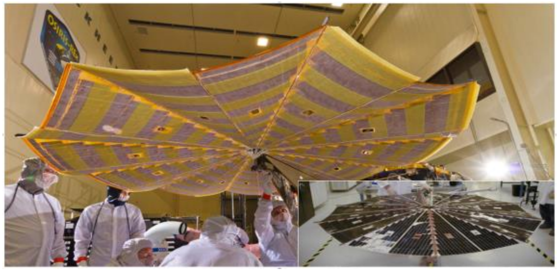


Azur Space, Triple Junction GaAs solar cells on flexible carrier

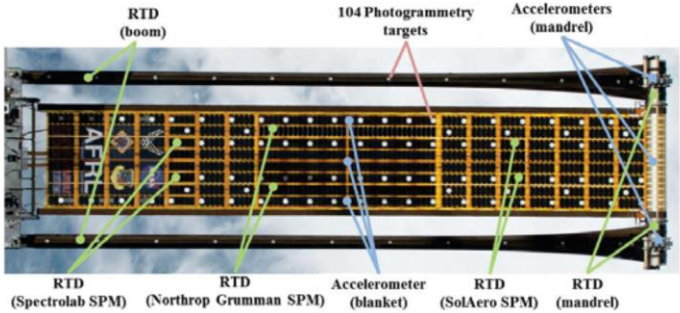
Flexible Solar Array Designs

- Bushing boundaries

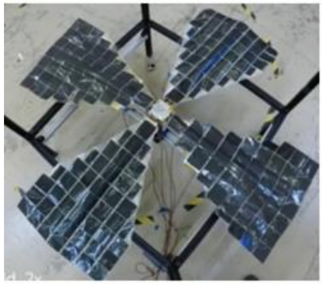
100 W/kg 30 kw/m^3	→	> 150 W/kg > 40 kw/m^3



ESKENAZI, Mike, et al. Promising results from three NASA SBIR solar array technology development programs, 2005



NASA ROSA Array https://www.nasa.gov/planetarydefense/dart

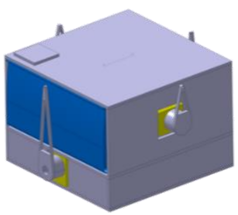


John A. Carr et. al., The Lightweight Integrated Solar Array and anTenna: 3rd Generation Advancements, and Beyond

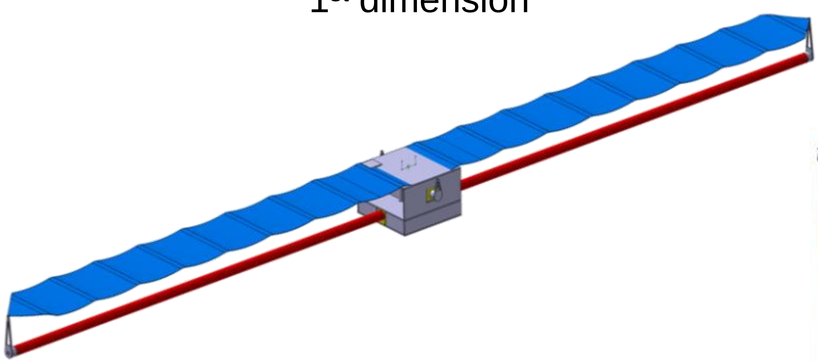
DLR‘s 2D Deployment Strategy

- Concept for sequential unfolding of the two dimensions of the membrane

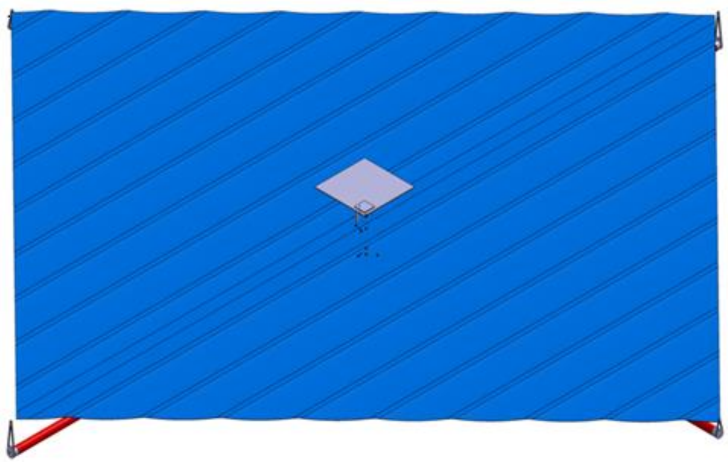
Stowed Configuration



Deployment of 1st dimension

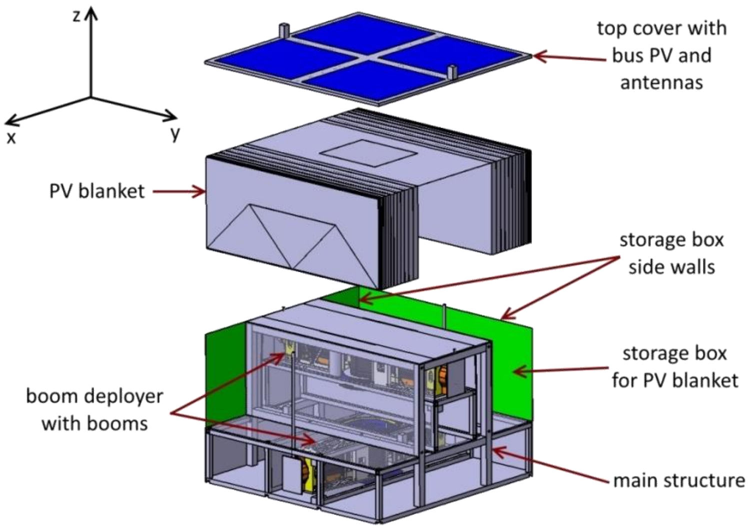


Deployment of 2nd dimension



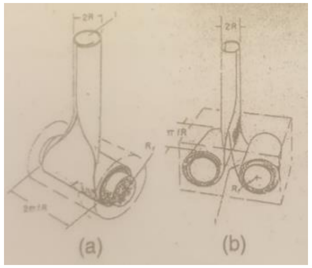
Overall Accommodation

- Sidewalls with hinges that, after release, fold the walls up out of the sail plane
- System and photovoltaic harness need to be routed through the centre

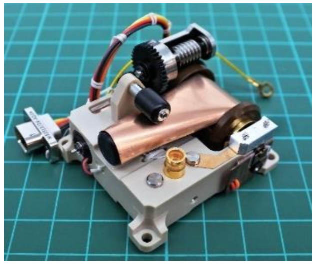


Booms

- Solutions depend on the size of the spacecraft
    - ➢Copper Beryllium Booms for small systems (a few square meter)
    - ➢CFK tubular booms for medium sized systems (a few 10 square meter)
    - ➢Articulated for large systems (e.g. ISS)



Sergio Pellegrino, *Deployable structures,* Springer, 2014.



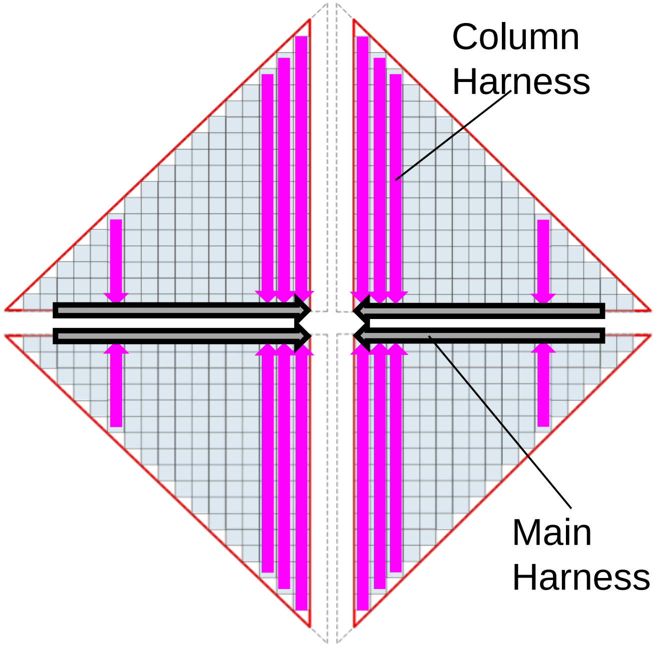
www.astronika.pl

DLR CFK Booms

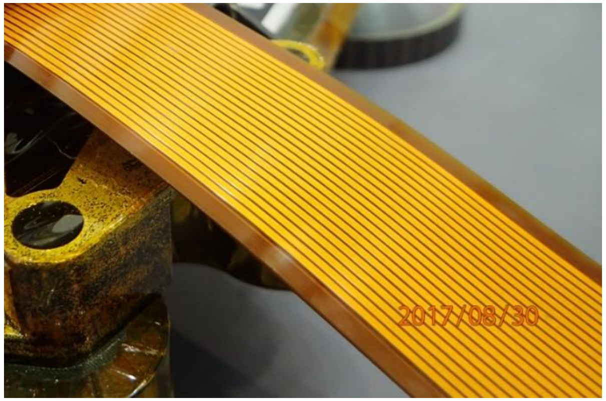
Courtesy of ATK/ ABLE Engineering

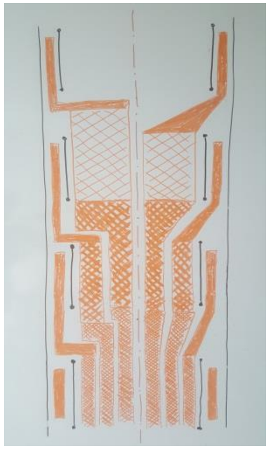
Overall Electrical Layout

- Column harness interconnects each generator
- For GoSolAr, the main harness leads to the centre were the photovoltaic characterization electronics is located
- Harness based on flexible PCB material
- Printed circuits as mesh for homogenous mechanical and thermal behaviour



Array harness concept



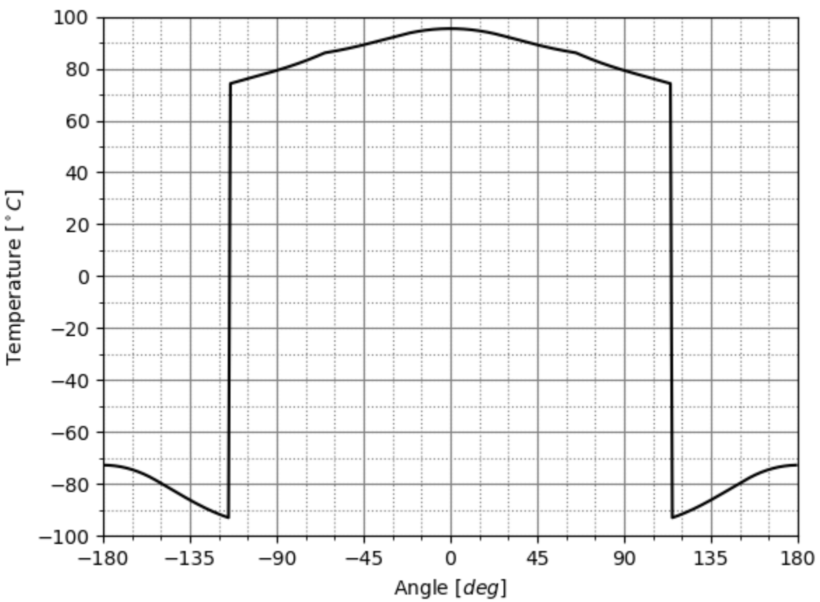


Harness Flex PCB design concepts

PV Blanket Thermal Design

- Temperature depend on design
- Temperature of the CIGS photovoltaic would be about 90°C
- High-ϵ SiO_2 coating on the front side
  - 2.2µm thickness
  - Dip coating using polysilazane
  - Significant increase of emissivity
  - Small influence on absorptance
  - Provides protection against atomic oxygen
  - Provides shielding against low energy protons
- Black polyimide **base membrane** on the backside as **radiator** material

	α	ϵ
CIGS without SiO2	0.89	0.38
CIGS with SiO2	0.91	0.77
Black Kapton	0.93	0.87



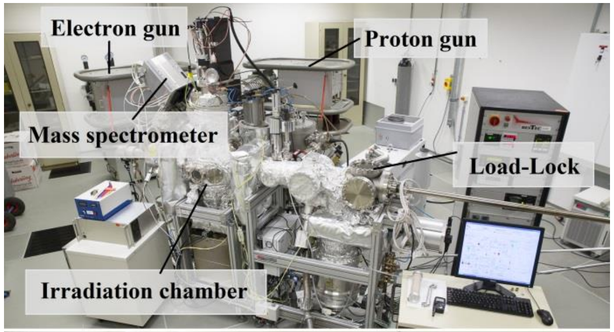
Testing and DLR Facilities

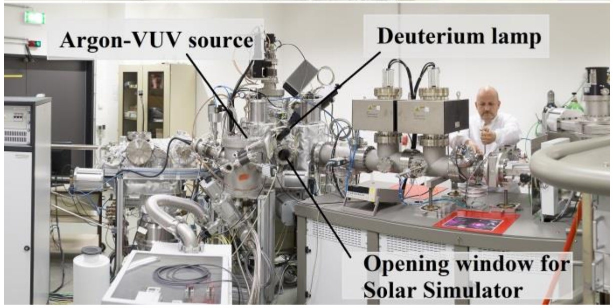
- 89 kN Shaker
- Pyroshock test stand during a shock initiation
- Closed recipient of the Space Simulation Chamber
- Complex Irradiation Facility with the different irradiation sources
- Deployment test rig

  - ➢ Standard qualification testing
  - ➢ Adapted to test very specific functions under certain environmental conditions

    - ➢ **Material Tests**
    - ➢ **Mission Simulation**
    - ➢ **Deployment Tests**

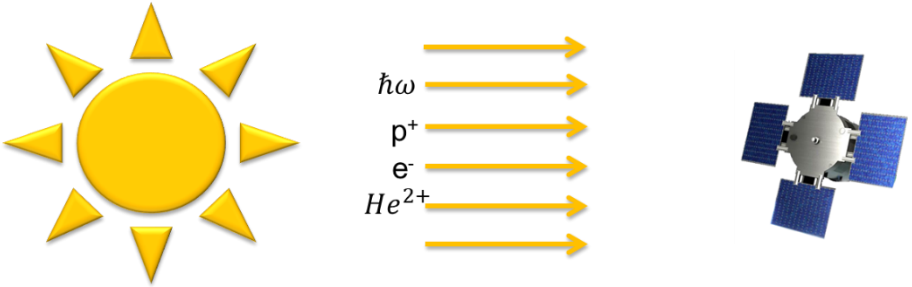






Material Tests - Radiation

- Spacecraft operate in a unique radiation environment that is very different to the environment on earth.

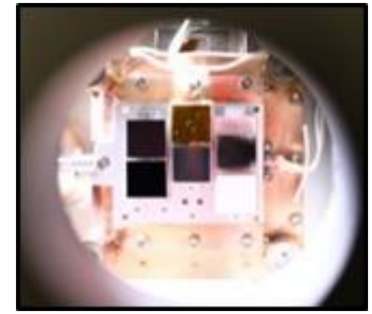


- Electromagnetic radiation (full spectrum not shielded by atmosphere)
  - ➢ Solar Constant $S_0 = 1361 \mathrm{W/m^2}$

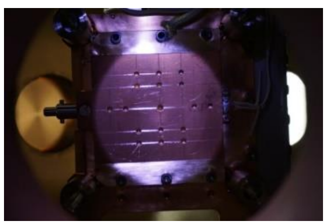
- Solar wind and solar energetic particles
  - ➢ Mainly protons, electrons and Helium ions (alpha particles)
  - ➢ Most particles have energies up to 10keV
  - ➢ Particle energies can also be several MeV

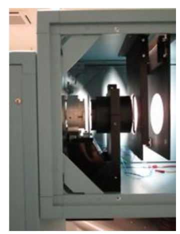
- Complex Irradiation Facility (CIF)
  - ➢ Study materials under space environment conditions

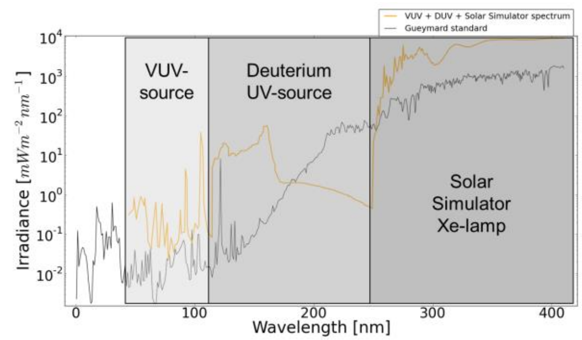
CIF



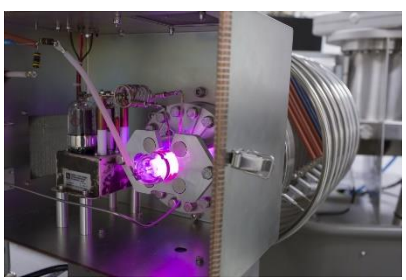
- Irradiated area: 80mm diameter
- Vacuum: < 10^{-8} mbar without VUV-source,
  < 10^{-6} mbar with VUV-source
- Temperature control: Heating with halogen lamps up to 450°C
  Cooling with thermostat -30°C
  Cooling with LN2 -170°C
- Electromagnetic sources: Argon VUV-source, Deuterium UV-source and Xenon-lamp

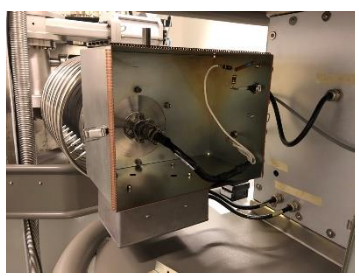






- Proton and electron accelerators





CIF	energy	current
e- / p+	2 to 10keV	1 to 100 nA
	10 to 100keV	0.1 to 100 µA

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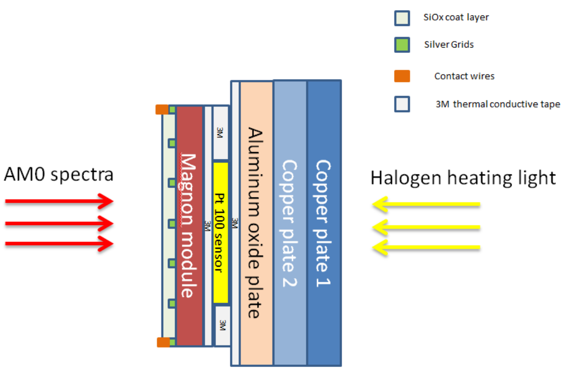
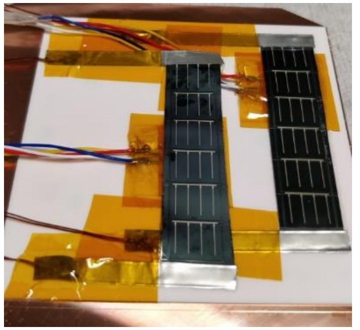
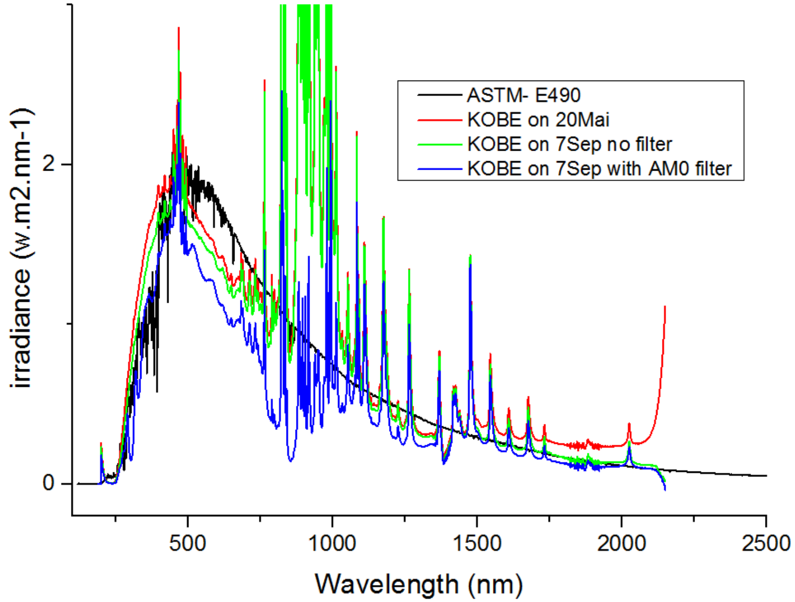
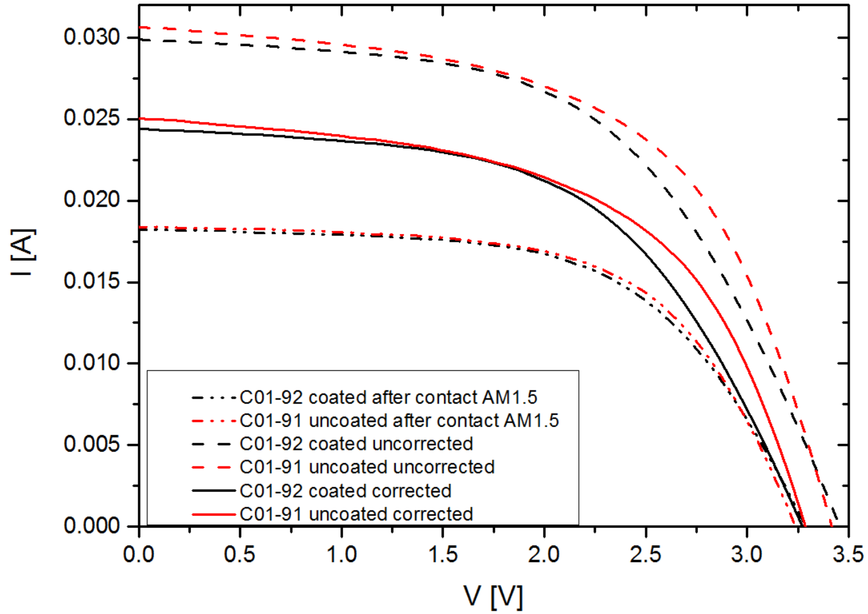
IV-Curves

- The CIF is also used to measure IV-curves of solar cells



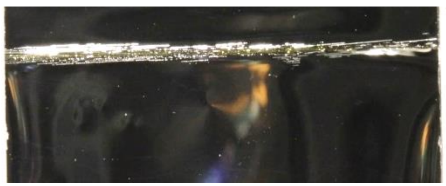


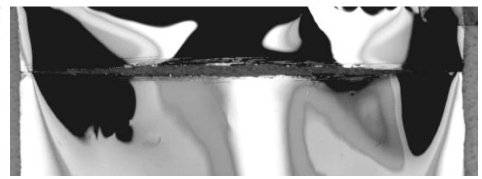




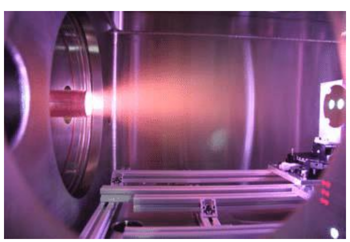
Atomic Oxygen Erosion

- Atomic oxygen erosion is a major material degradation factor in Low Earth Orbits
- While binding energy of metal atoms is high enough to prevent erosion, polymer materials are eroded!
- For flexible solar array designs different polymer thin-films are used, polyimides (e.g. Kapton), polyester (e.g. Mylar), fluoropolymers (e.g. FEP)
- Coatings with metals and oxide enhance material properties with respect to erosion.

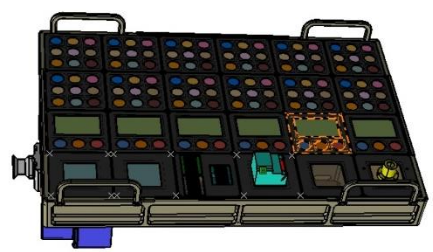




- Atomic oxygen test are required (see upcoming presentation of Bohan Wu and Adrian Tighe)



ESA/ESTEC LEOX Facility



Euro Material Exposer Activity (ESA)

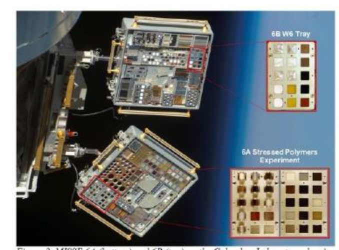
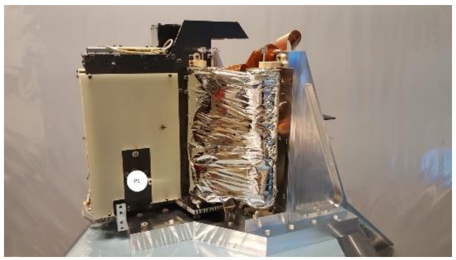


Figure 2. MISSE 6A (bottom) and 6B (top) on the Columbus Laboratory showing the locations of trays W2, W3 and W6.

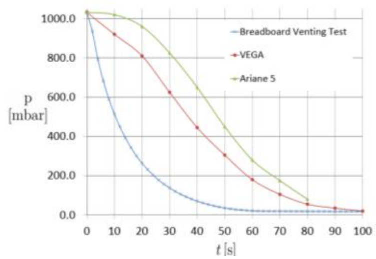
Materials International Space Station Experiment (NASA)

System Level Tests

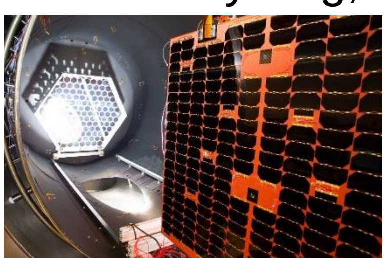
- Mechanical Vibration

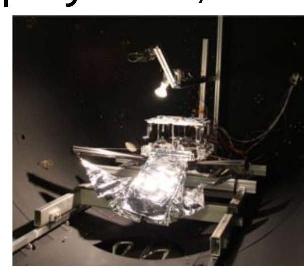


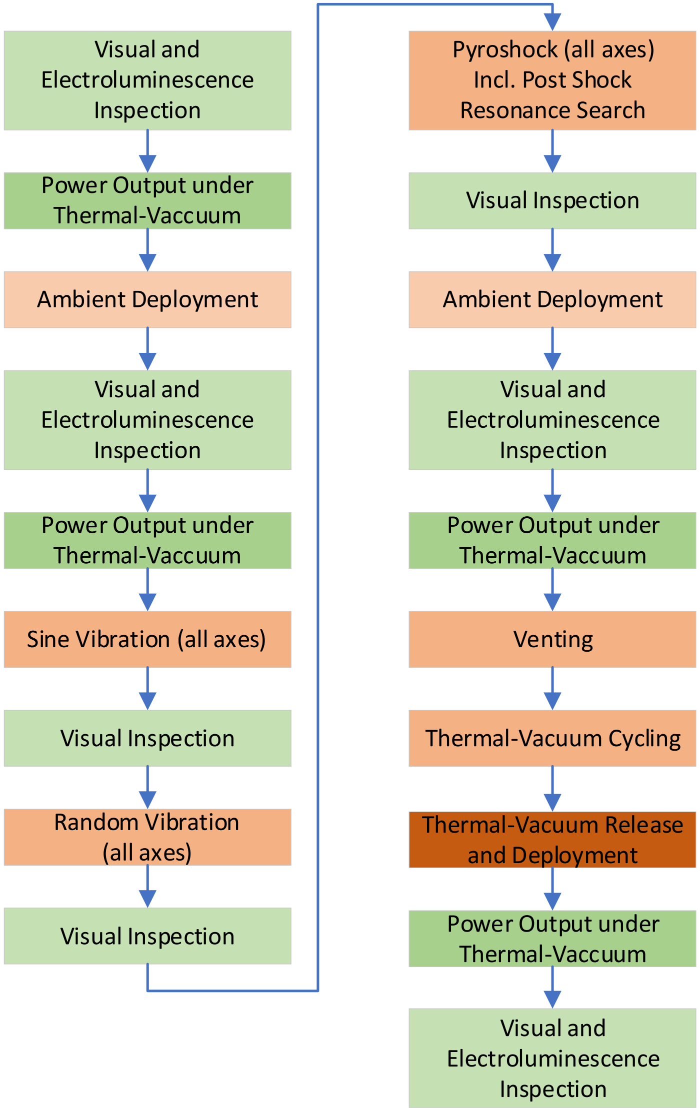
- Venting



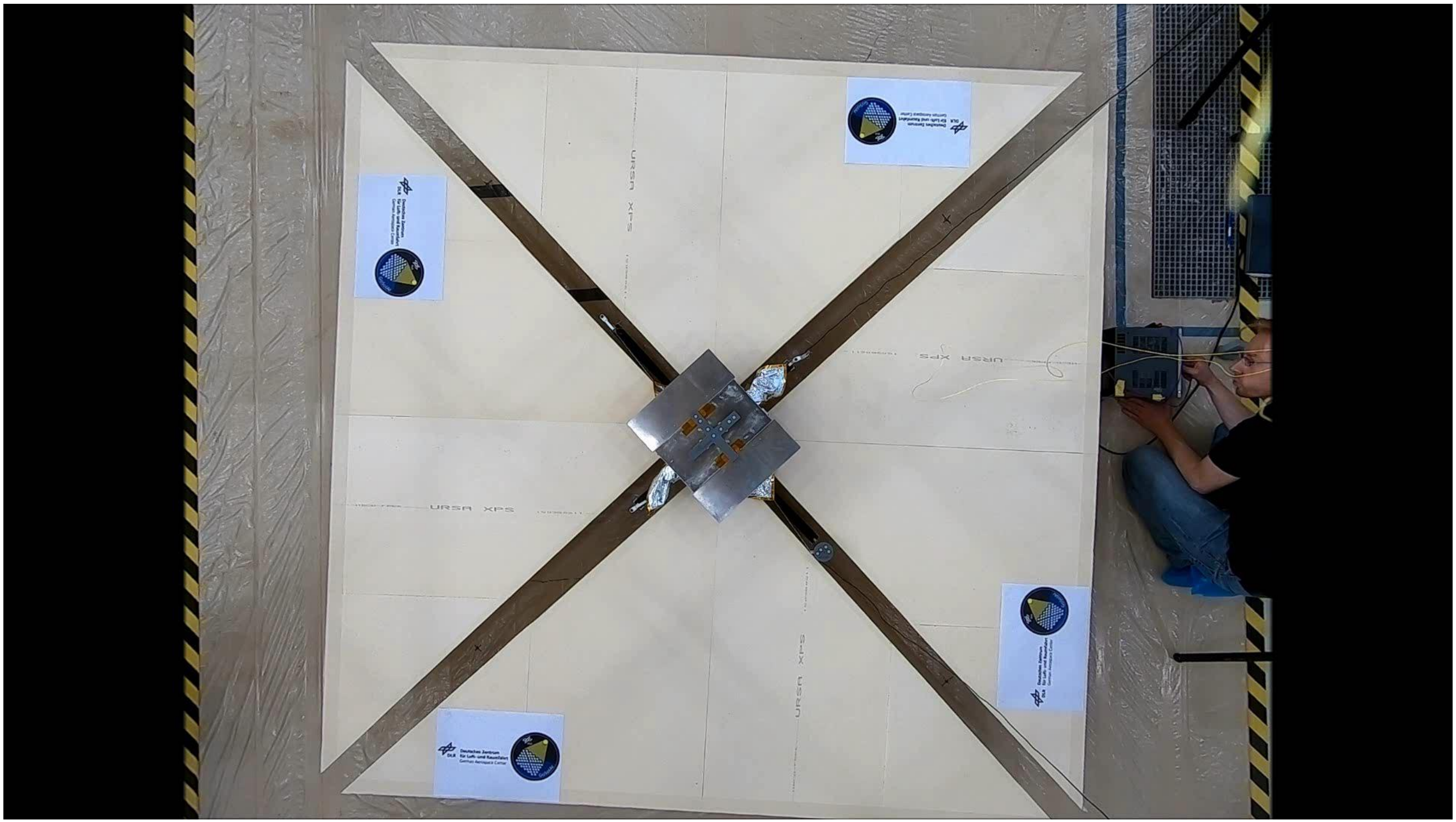
- Thermal Cycling, deployment, in-orbit simulation



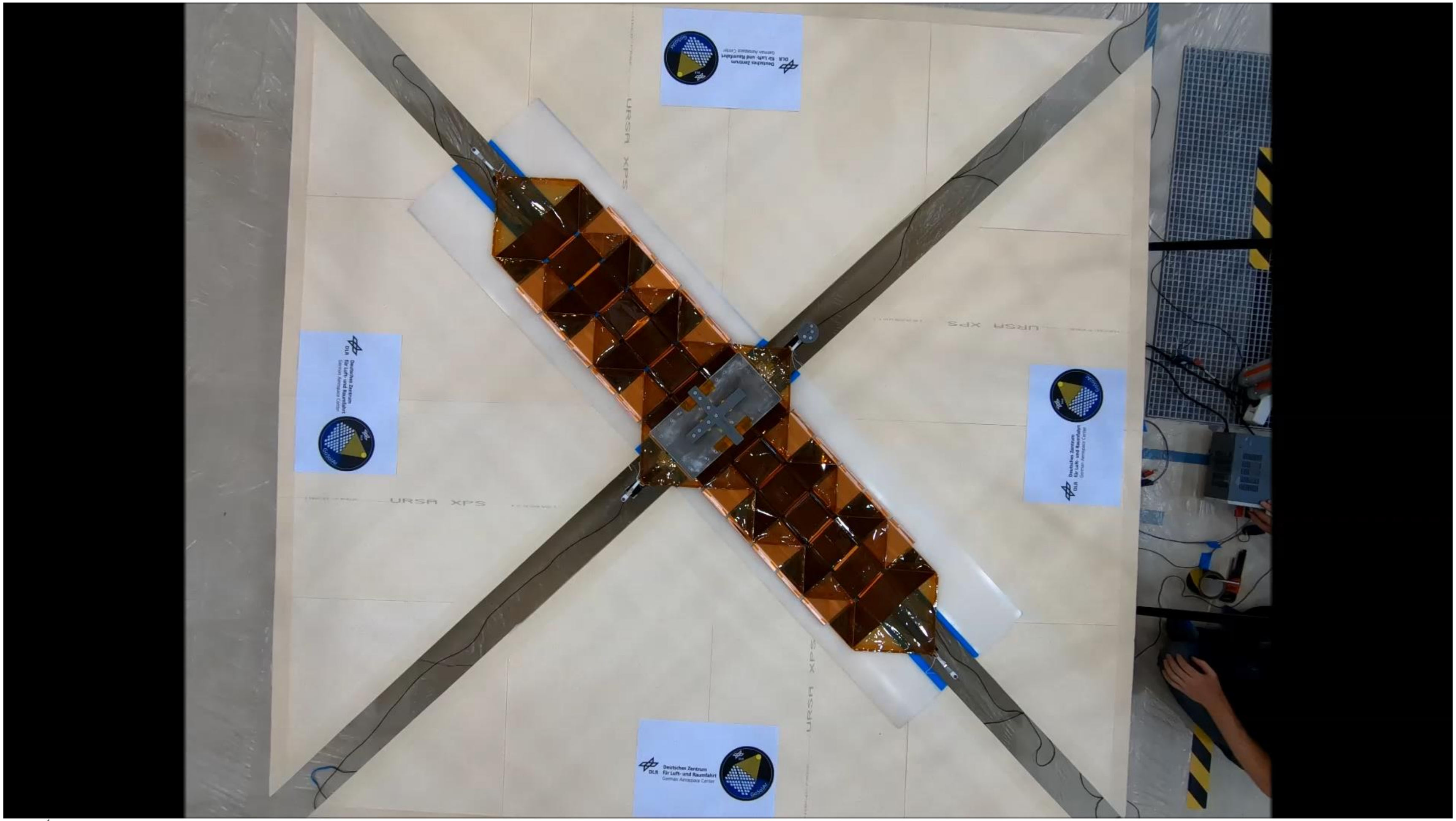




Deployment Tests - 1st Dimension



Deployment Test – 2nd Dimension



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Conclusion

- A lot of effort is put into the development of new deployment concepts and solar array designs in order to make better use of available photovoltaic technology.
- This requires flexible solar array designs using novel materials.
- The used materials are often polymers that are degrading under the space radiation and atomic oxygen environment.
- Extensive testing is required to qualify new materials and technologies for space applications.

And what is beyond solar cells?