# C H A R D E M

# EXPERIMENTAL INVESTIGATIONS ON THE DEMISABILITY OF SPACE RELEVANT MATERIALS

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# What is CHARDEM?

- Characterisation of Demisable Materials
- ESA-funded TRP project
- That targets the demisability on material level
- With four project partners

HTG HYPERSCHALL TECHNOLOGIE GÖTTINGEN GMBH

QinetiQ

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OGI

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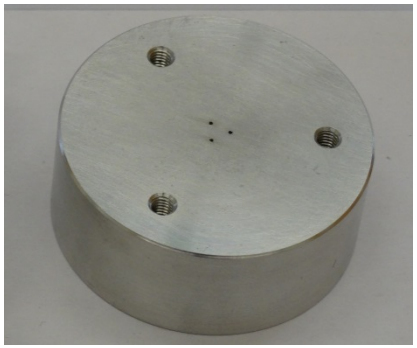
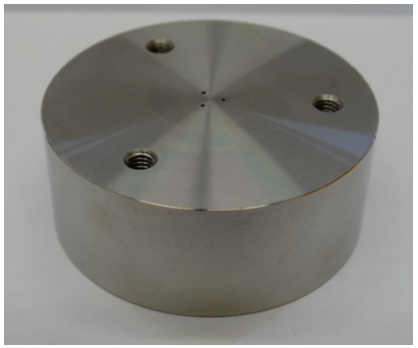
# CHARDEM - Materials

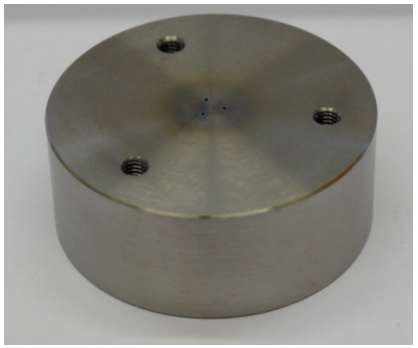
Widely used and/or prominent representatives chosen and manufactured by QinetiQ:



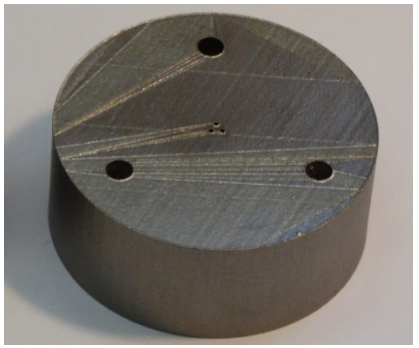
**Aluminium alloy 7075**



**Steel AISI 316L**



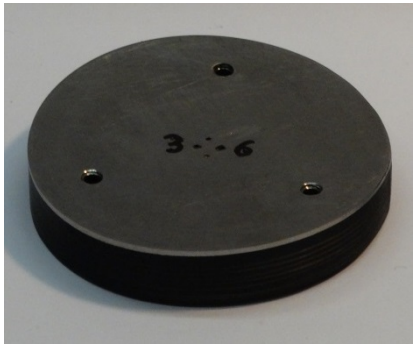
**Titanium alloy Ti6Al4V**



**Titanium 3D printed**

**Silicon Carbide**

**CFRP**



**High Pres. Tank**

**Solar Panel**

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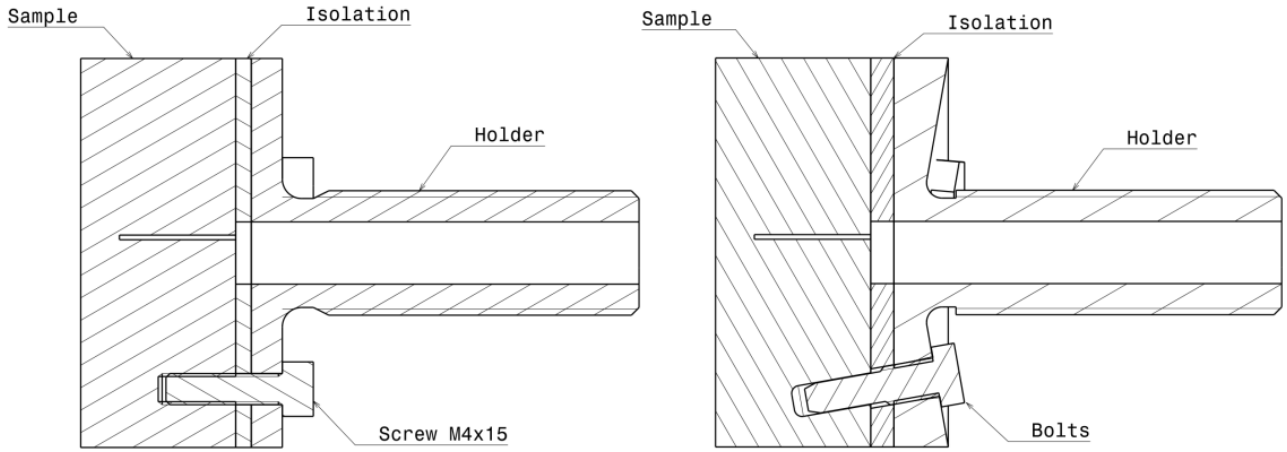
# Standard demisability test procedure

Developed by HTG, consists of:

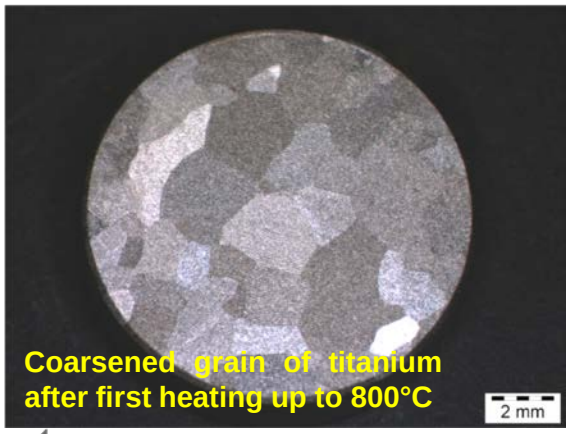
- Measuring of all demise relevant thermophysical properties
- Demise testing in high enthalpy wind tunnels with standardized samples and test conditions
- Post-test analyses depending on material and open questions from demise testing
- Numerical rebuilding of the wind tunnel experiments

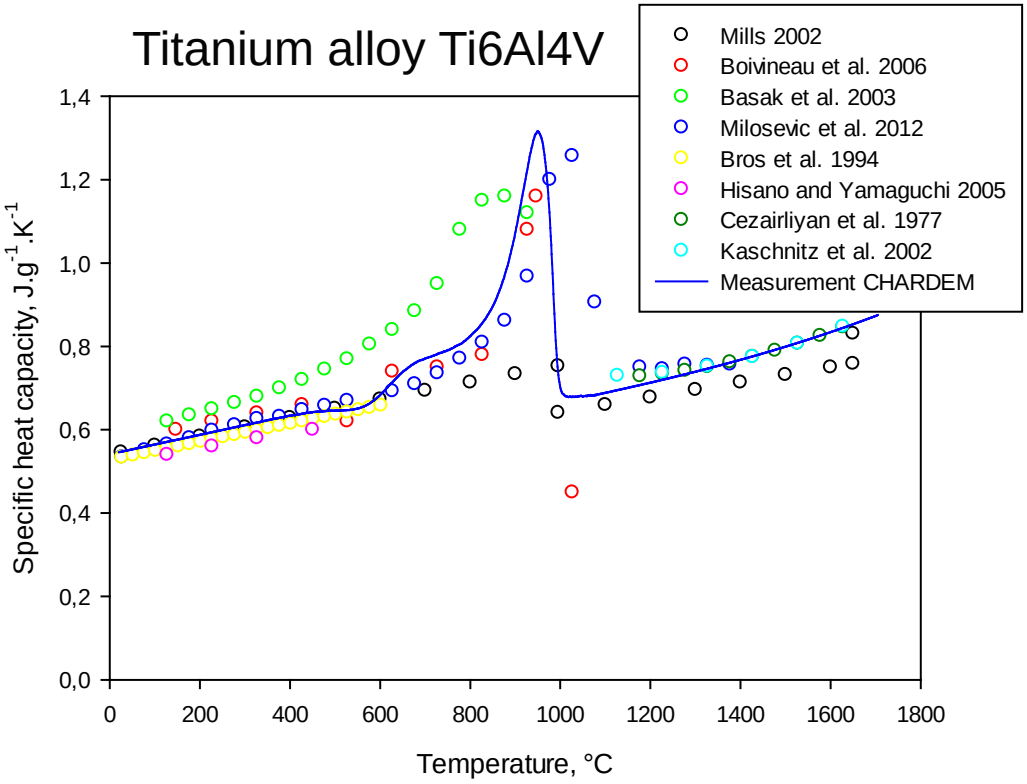



# Thermophysical characterization

Intensive analyses were conducted by ÖGI, including:

- Specific heat capacity, heat of solid state phase transitions and heat of fusion
- Density and volume expansion
- Thermal conductivity
- And detail specific additional analyses

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# Demise testing

26 demise experiments were conducted at LBK facilities of DLR.

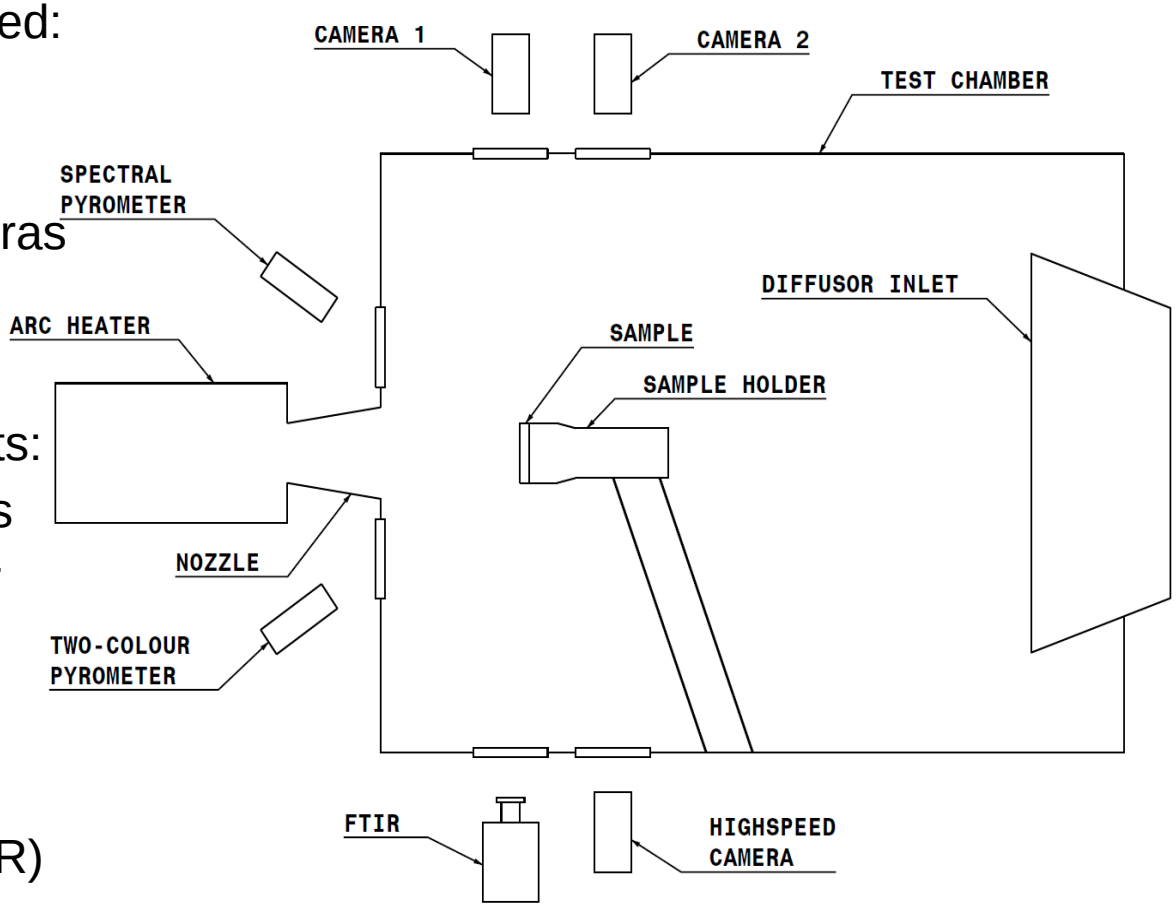
- Low heat flux and/or high heat flux tests, depending on demisability of the material
- Conditions determined by reference missions defined by ESA; re-entry from circular low earth orbit and highly eccentric orbit (131,000 x 75 km)

| **Test condition** | | **L2K** | **L3K** |
|---|---|---|---|
| **Reservoir temperature** | [K] | 4356 | 6462 |
| **Specific enthalpy** | [MJ/kg] | 8.7 | 15.9 |
| **Free stream static pressure** | [hPa] | 1.43 | 1.13 |
| **Free stream static temperature** | [K] | 567 | 601 |
| **Free stream velocity** | [m/s] | 2984 | 4069 |
| **Measured pitot pressure** | [hPa] | 61.0 | 84.4 |
| **Measured cold wall heat flux** | [MW/m²] | 1.2 | 2.3 |
| **Maximum test duration** | [s] | 200 | 400 |

# Demise testing

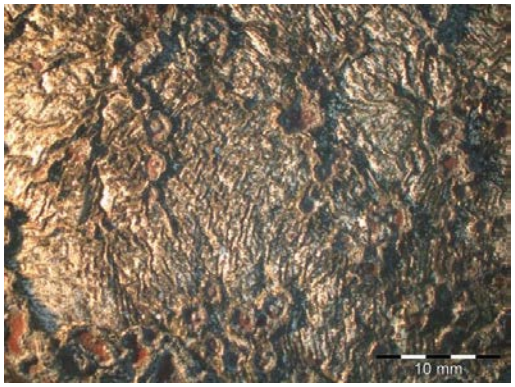
Measurements techniques used:

- Demise and recession observation by video cameras and high speed camera
- Temperature measurements:
  - Internal thermocouples
  - Spectral and two-color pyrometer
  - Infrared camera
- Infrared spectroscopy (FTIR)

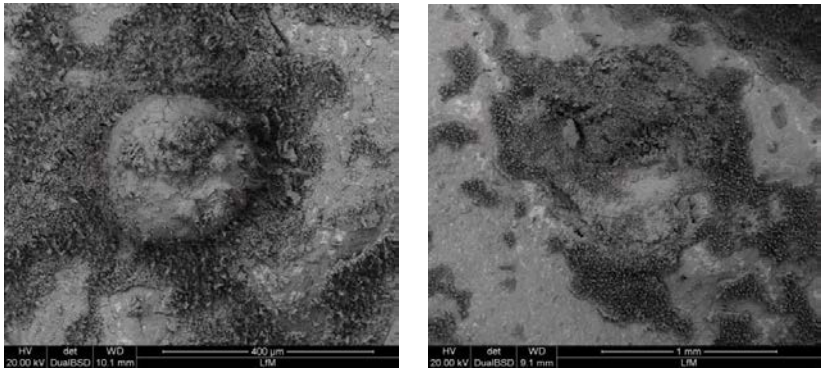



# Post test analysis

- Post-test analyses of metallic samples (AA7075, AISI 316L, Ti6Al4V) was conducted at ÖGI.
- CFRP and SiC samples were analyzed at institutes dedicated to the material category
- Techniques included
  - Scanning electron microscopy
  - Laser Raman microprobing
  - Hardness testing
  - Infrared spectrometry
  - Scanning accoustic microscopy
  - And many more




Surface of tested steel sample

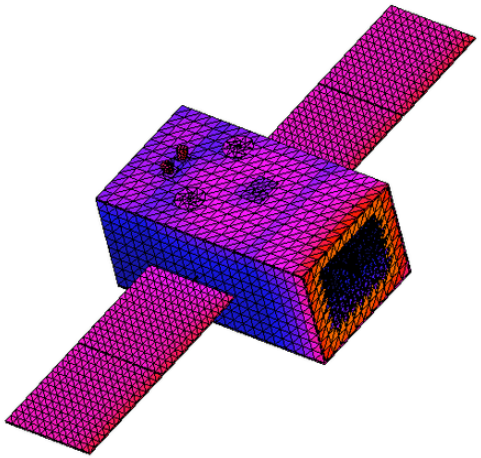


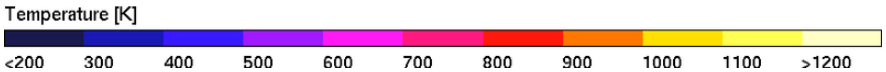
Intact (left) and collapsed (right) “bubble” on the surface of sample above

# Numerical simulation

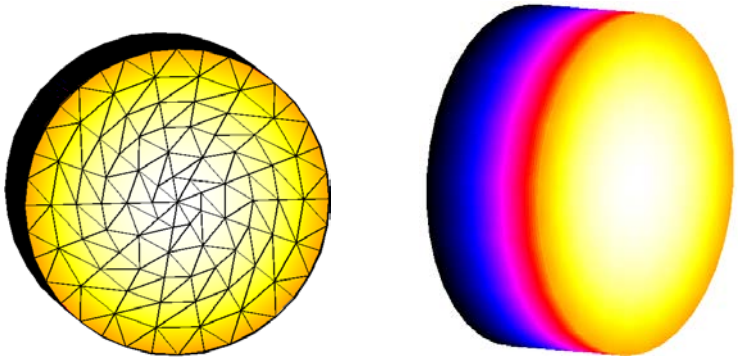
Demise experiments were simulated by HTG

- Using SCARAB (state-of-the-art demise simulation tool)
- And the thermophysical data gathered by ÖGI as well as the old data of the tool






SCARAB simulation of complete satellite



Numerical simulation of wind tunnel test, temperature gradient normal to surface

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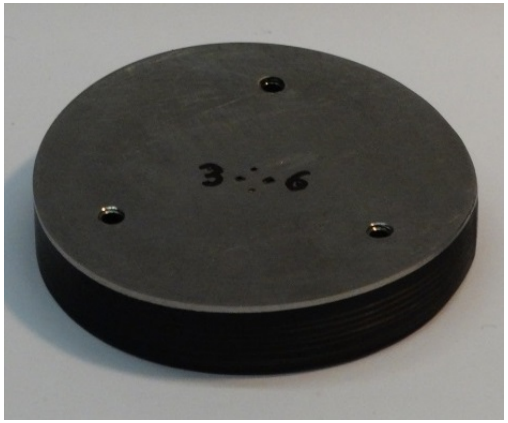
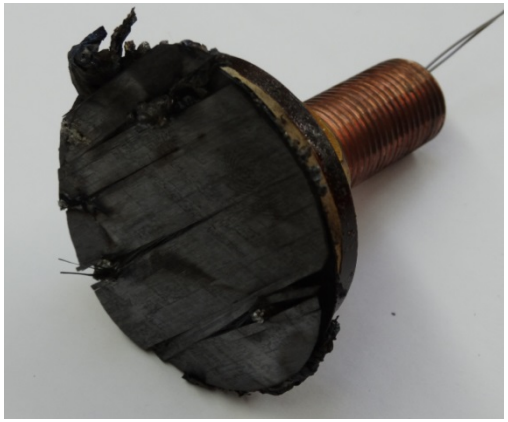
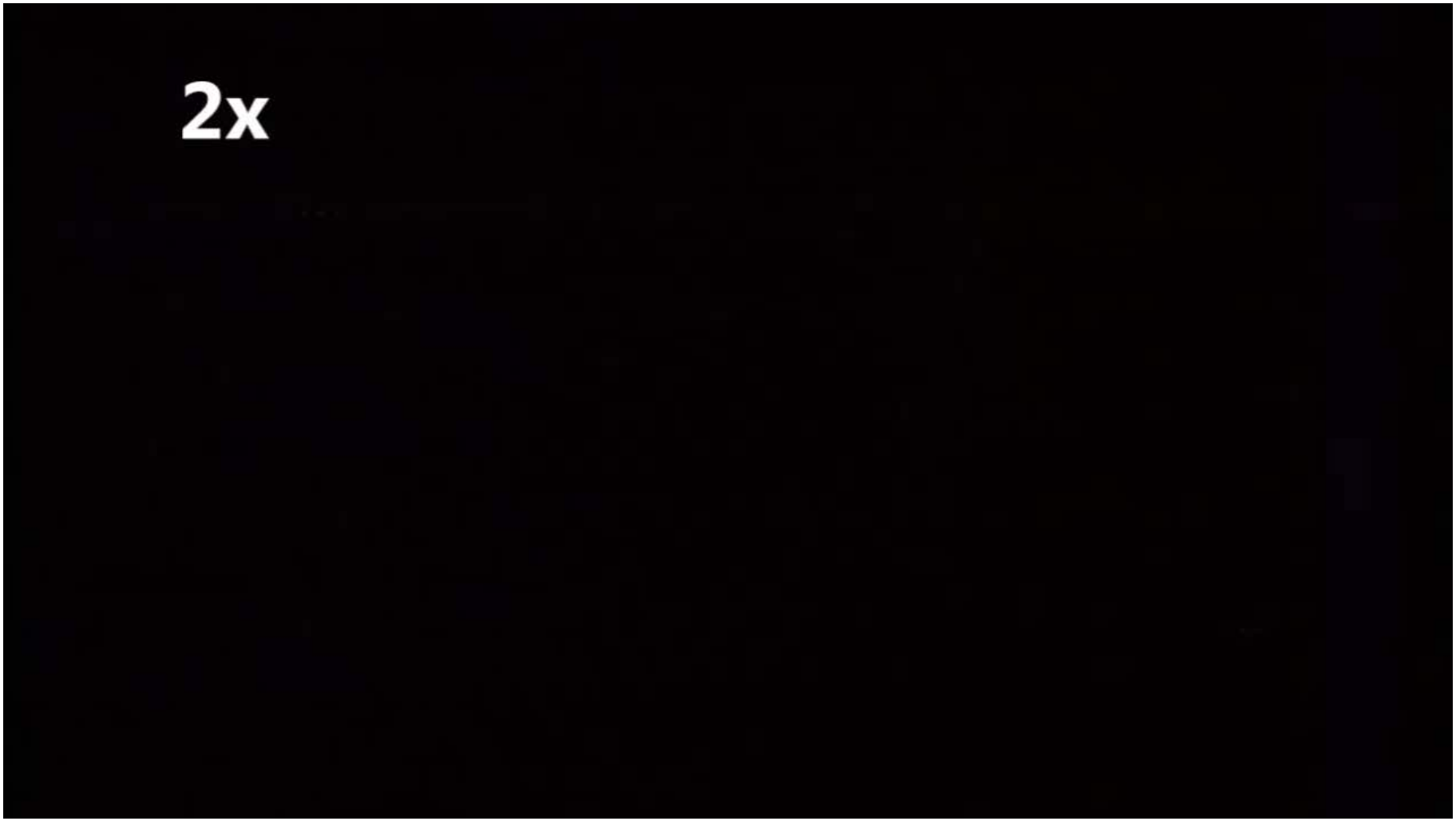
# Example – CFRP based samples

Three different types of CFRP based samples:

| Monolithic CFRP | High pressure tank | Solar panel |
| --- | --- | --- |
|  |  |  |
|  |  |  |

# Example – Monolithic CFRP, close-up

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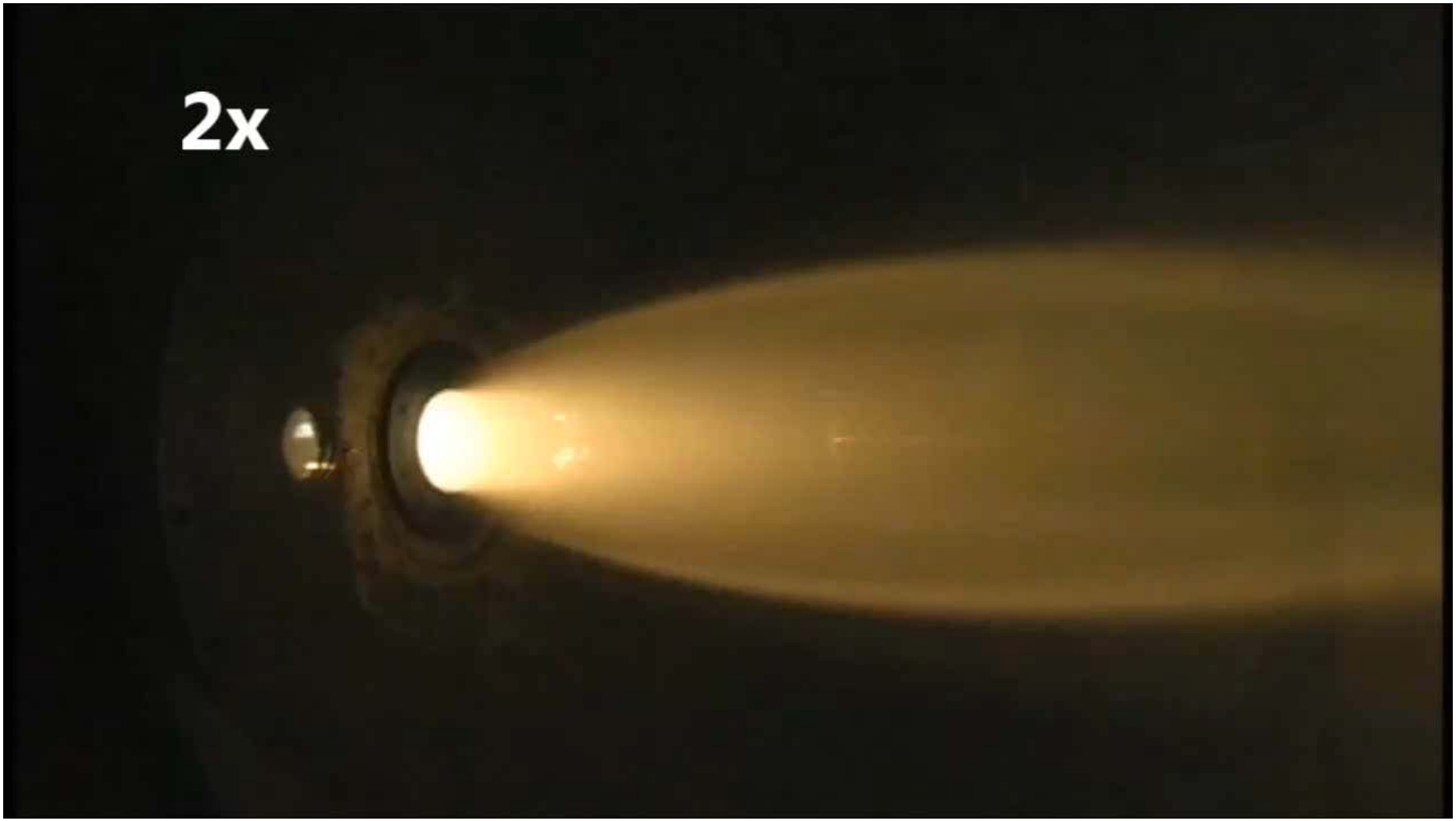
# Example – Monolithic CFRP, wide view

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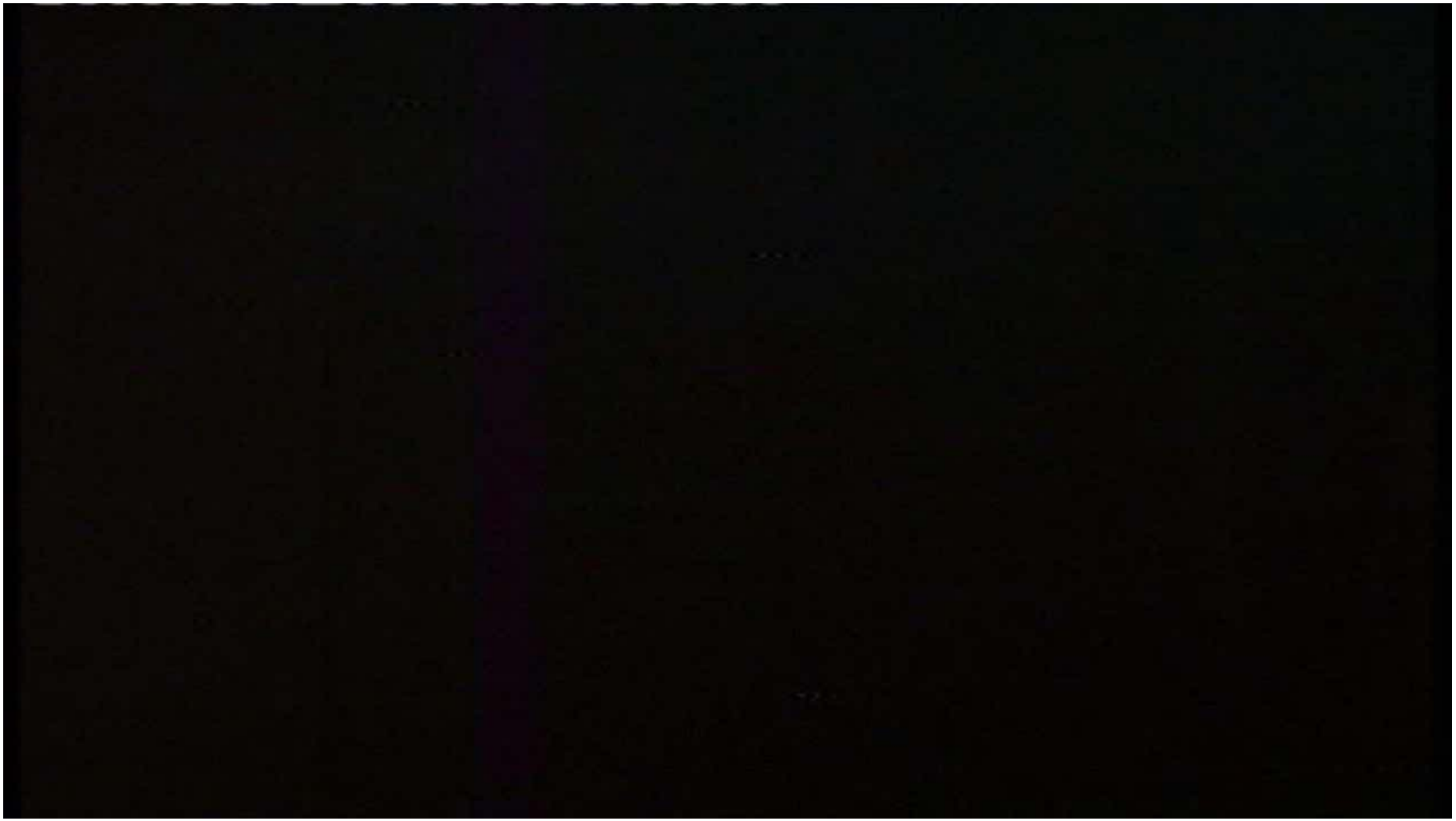
# Example – High pressure tank, close-up



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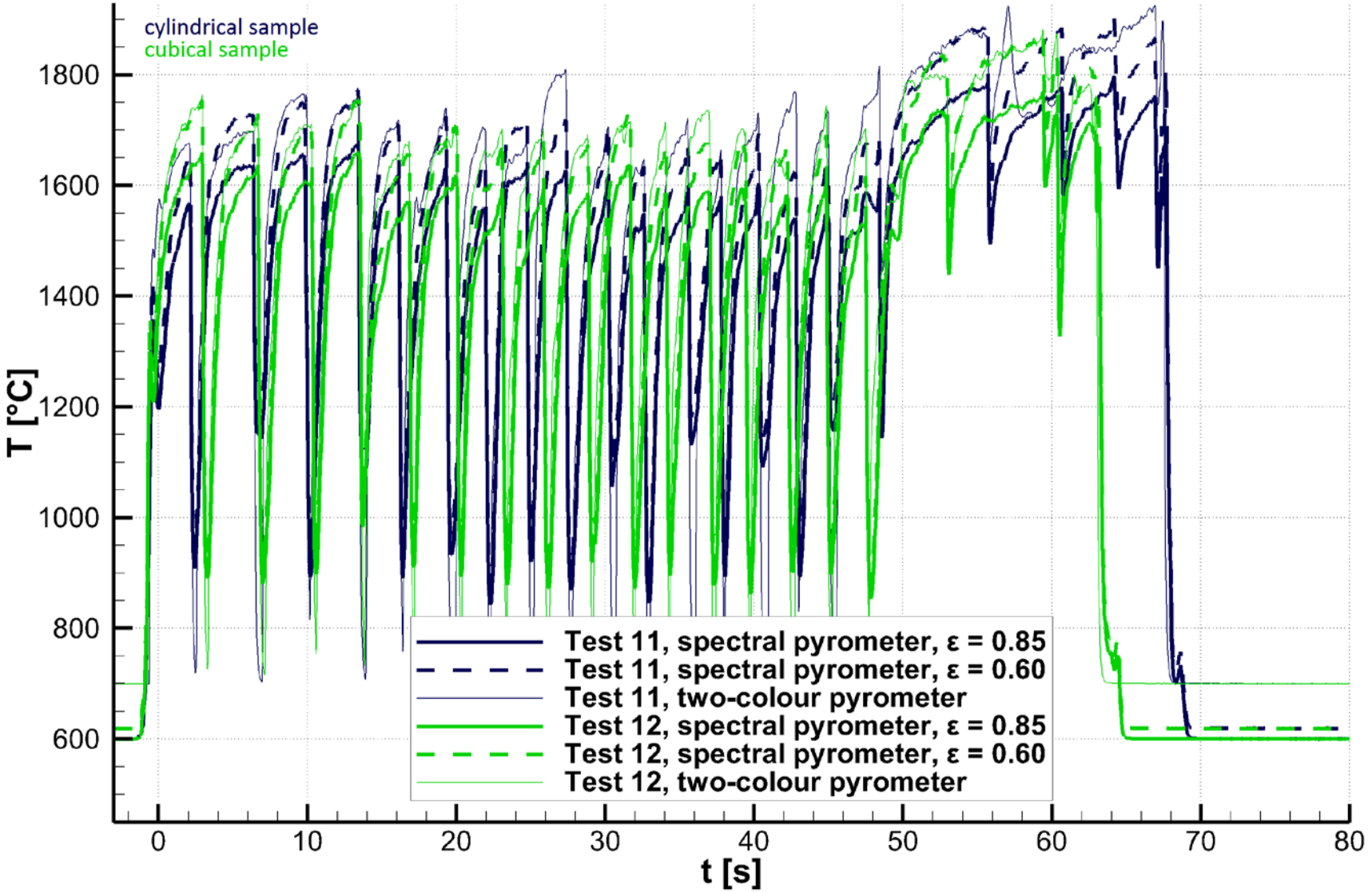
# Example – Monolithic CFRP, pyrometers

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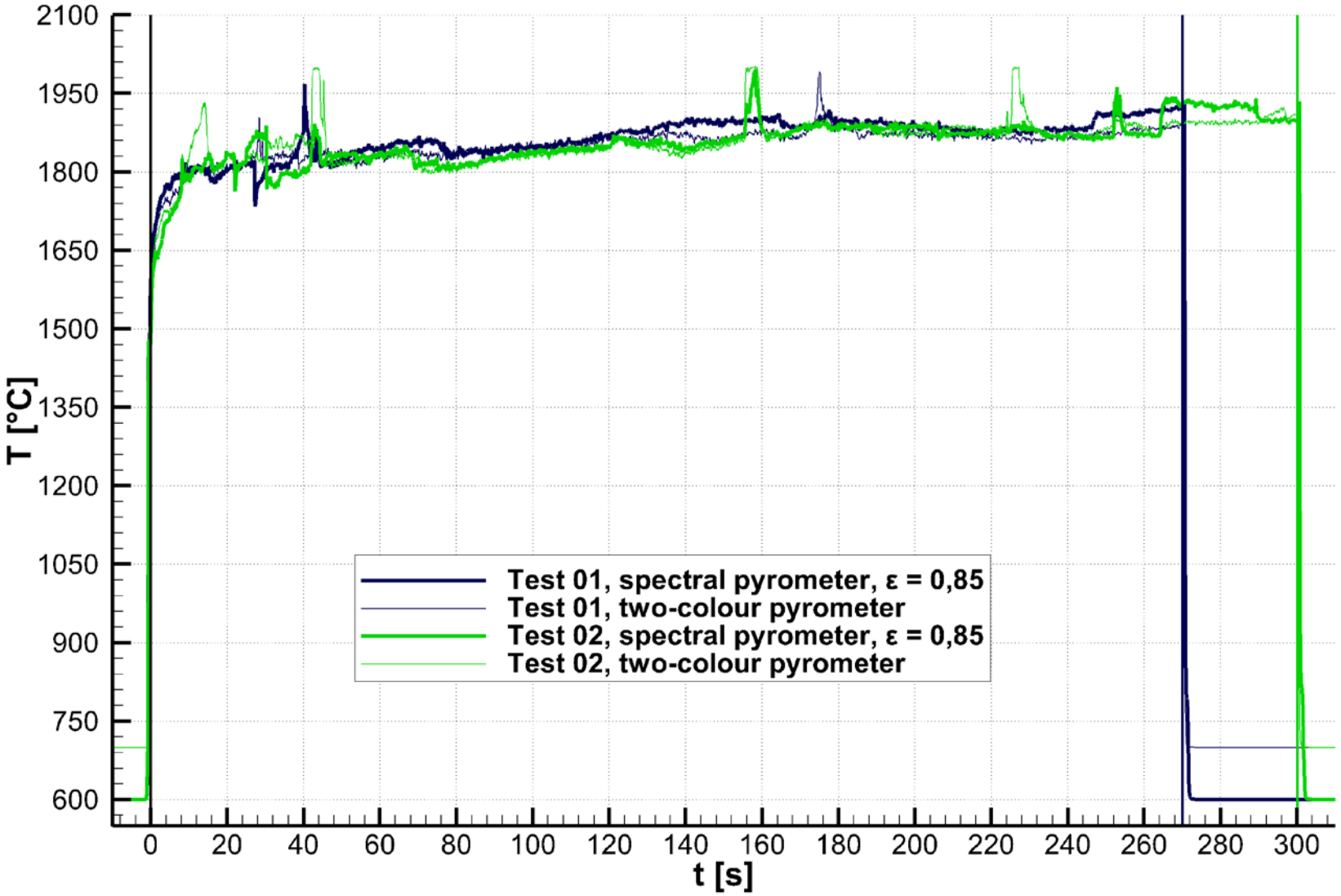
# Example – Tank sample, pyrometers




# Example – CFRP samples after testing

# Example – CFRP based samples

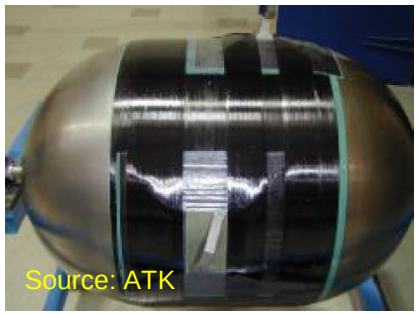
"Old CFRP approach":

- Use of metallic material model, assumption of instant burn up at certain temperature
- Constant heat flux
- Radiation depending only on surface temperature

→ Resulting demisability comparable to aluminum

Reality:

- Pyrolysis of matrix
  - Chemical heat sink
  - Effectively transpiration cooling
  - Reducing heat flux
  - Changing surface emissivity, catalycity, roughness, …
- Oxidation of fiber/matrix
  - Chemical heat source
  - Depending on oxygen availability
- Different macroscopic demise behavior
  - Slow burn up limited by oxygen or
  - Fast blow off of dried fibers





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# Example – CFRP based samples

New CFRP modelling approach (SCARAB*) :

- CFRP composed of two materials (fiber and matrix)
- Separate calculation of both
- Demise of matrix through pyrolysis and slow oxidation of dry fibers

| **Mass of sample** | **CFRP** | **Tank** |
|---|---|---|
| Measured, before test | 48.7 g | 32.7 g |
| SCARAB, before test | 48.1 g | 32.6 g |
| Measure, after test | 16.6 g | 10.3 g |
| SCARAB, after test | 41.6 g | 8.9 g |

*B. Fritsche, *Modelling the Thermal Decomposition of Carbon Fibre Materials During Re-Entry*, 6th European Conference on Space Debris

# Conclusions and outlook

- A lot of data has been gathered that´s both valuable and surprising
- Big gaps in knowledge and understanding of all types of materials have been unveiled
- Potential for increasing demisability has been found
- Website and database are in preparation
- Final meeting will take place soon (ESTEC, 7$^{th}$ of June)