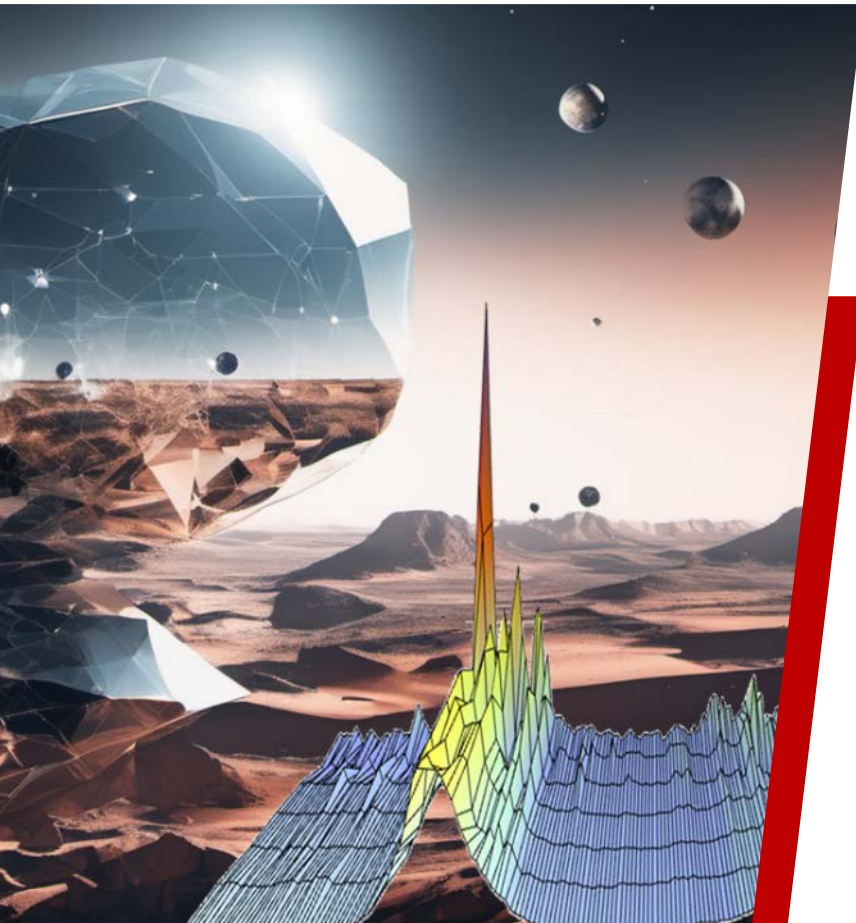




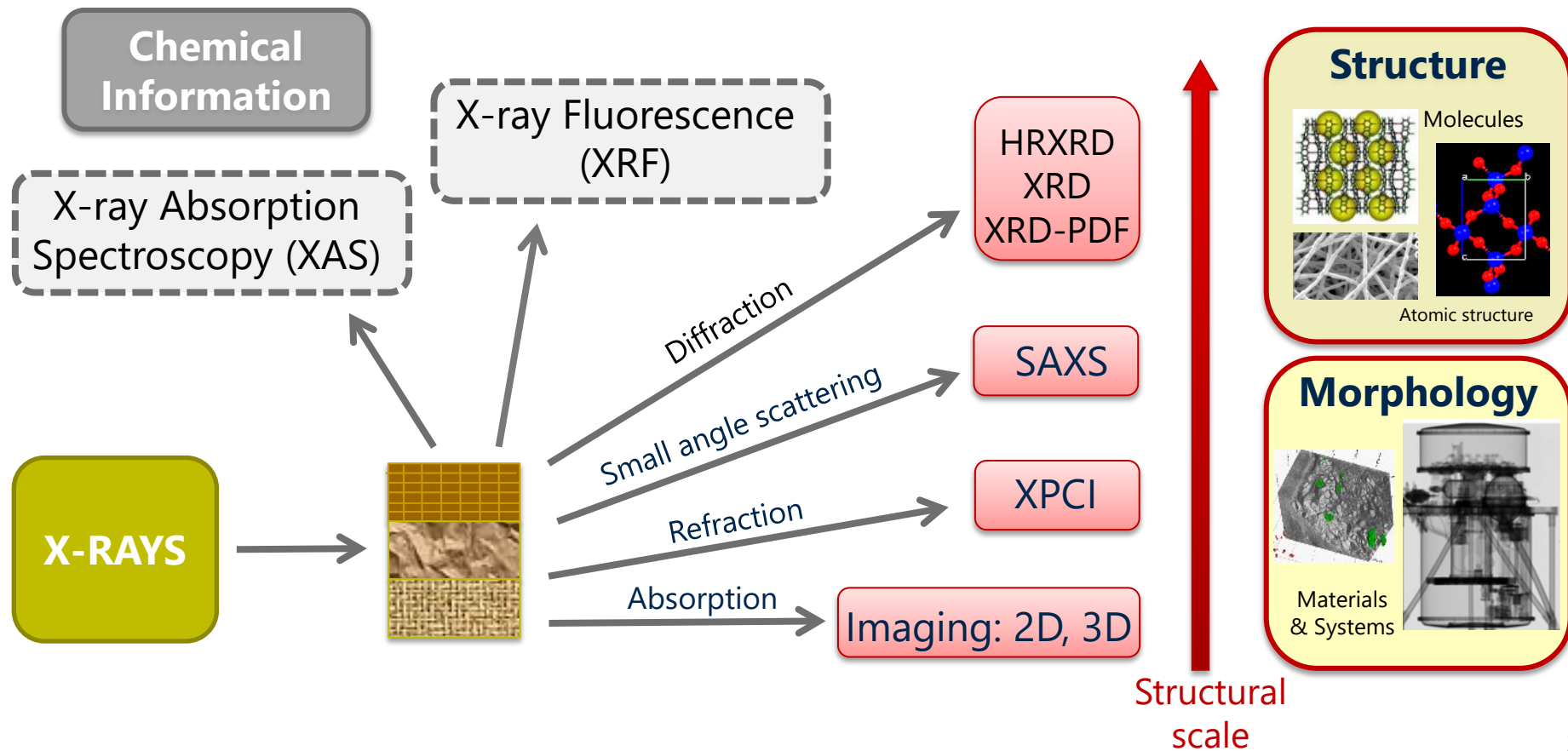
Materials for Space:

Microgravity research at the ISS
and integration of results into
manufacturing processes

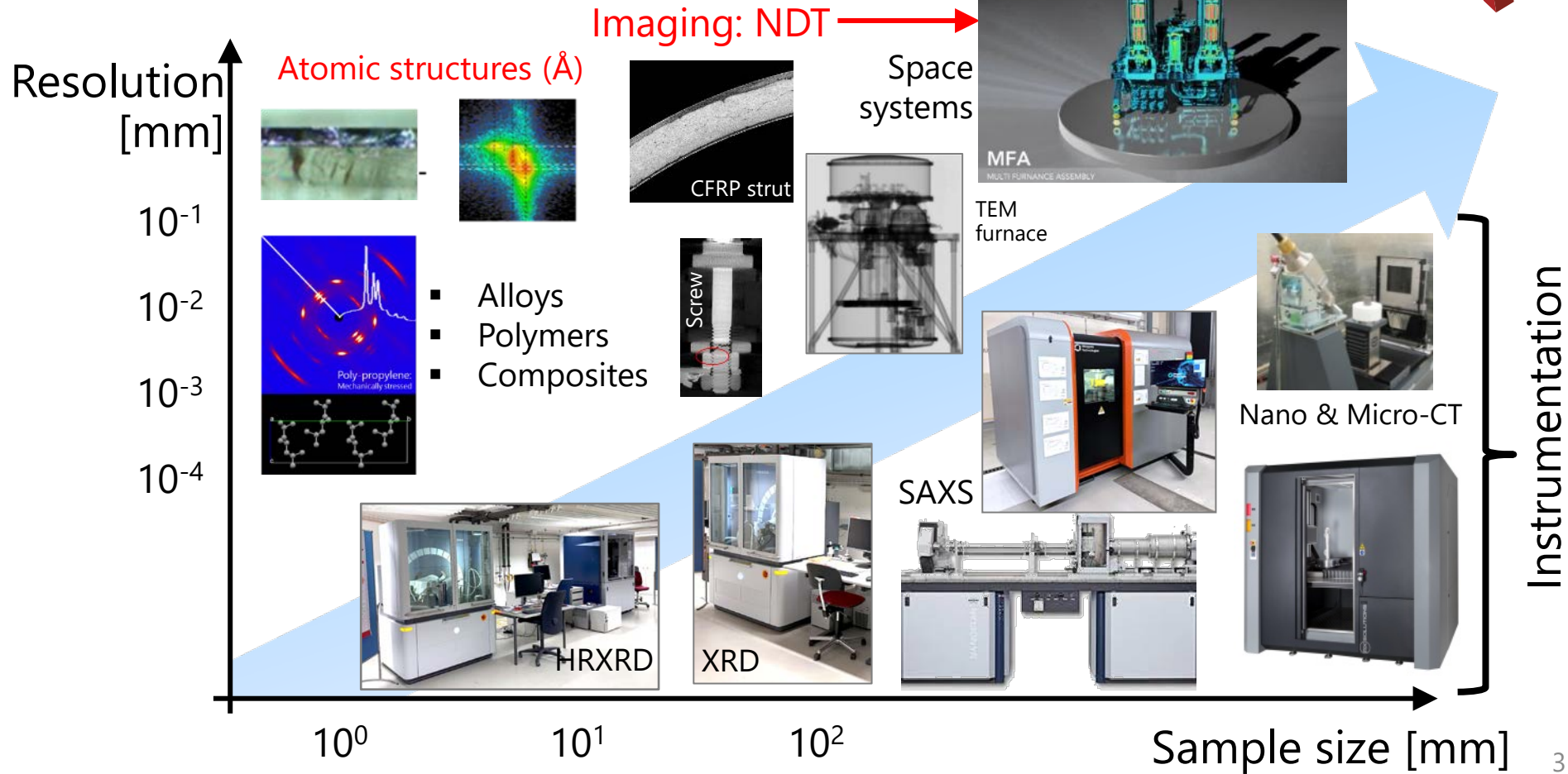
Prof. Dr. Antonia Neels
Empa, Center for X-ray Analytics

The Center for X-ray Analytics:

X-ray expertise for a holistic understanding of materials



Expertise and Infrastructure

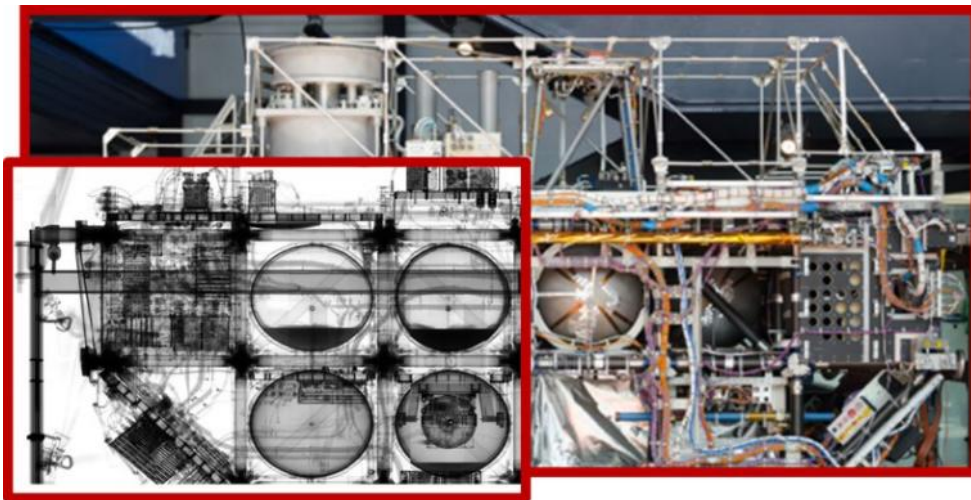


The EURECA satellite: post-flight investigations



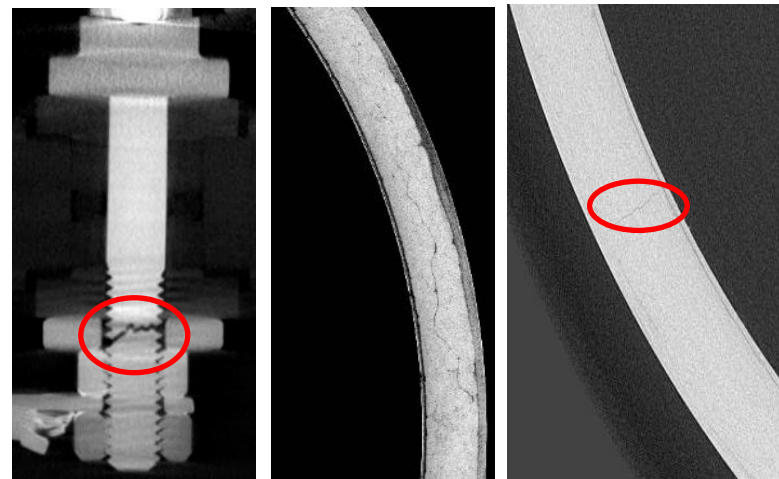
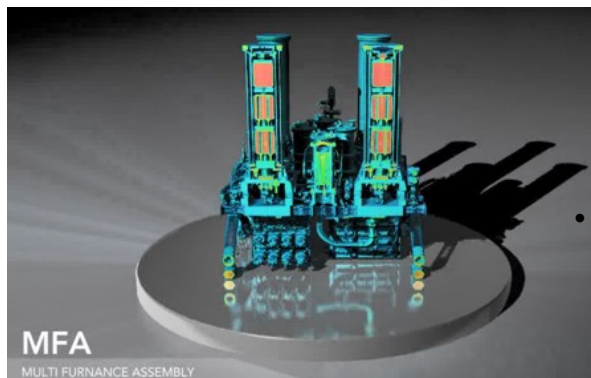
NDT on large scale space objects: the EURECA satellite

- Defect analysis in:
 - metallic **polycrystalline** parts
 - polymers



▪ X-ray absorption image

▪ 3D CT



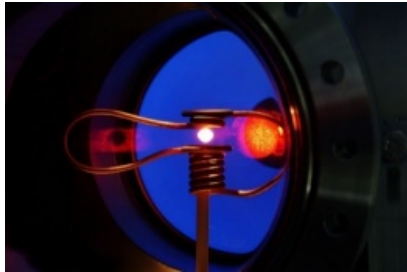
• "Multi-scale and multi-energy non-destructive X-ray analysis of the European Retrieval Carrier (EURECA)", R. Zboray, C. Rössli, A. Flisch, M. Plamondon, R. Kaufmann, C. von Deschwanden, K. Zwiack, T. Lüthi, T. Bandi, G. Bourban, V. Gass, D. Amstutz, J. Moran, A. Dommann, A. Neels, Acta Astronautica, **2025**, 235, 90-100.
<https://doi.org/10.1016/j.actaastro.2025.05.042>.

<https://www.youtube.com/watch?v=BP9BzyXx3S4>

Materials for Space: Properties of Metallic Glasses



1. Experiments on board the ISS

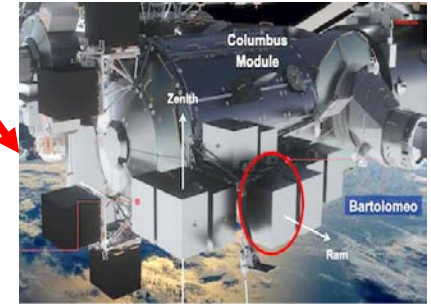


Electro Magnetic
Levitation (EML) furnace



Project partners from:
CH, DE, FR, IT, CA, UK, PL, US, NL

2. Experiments outside the ISS

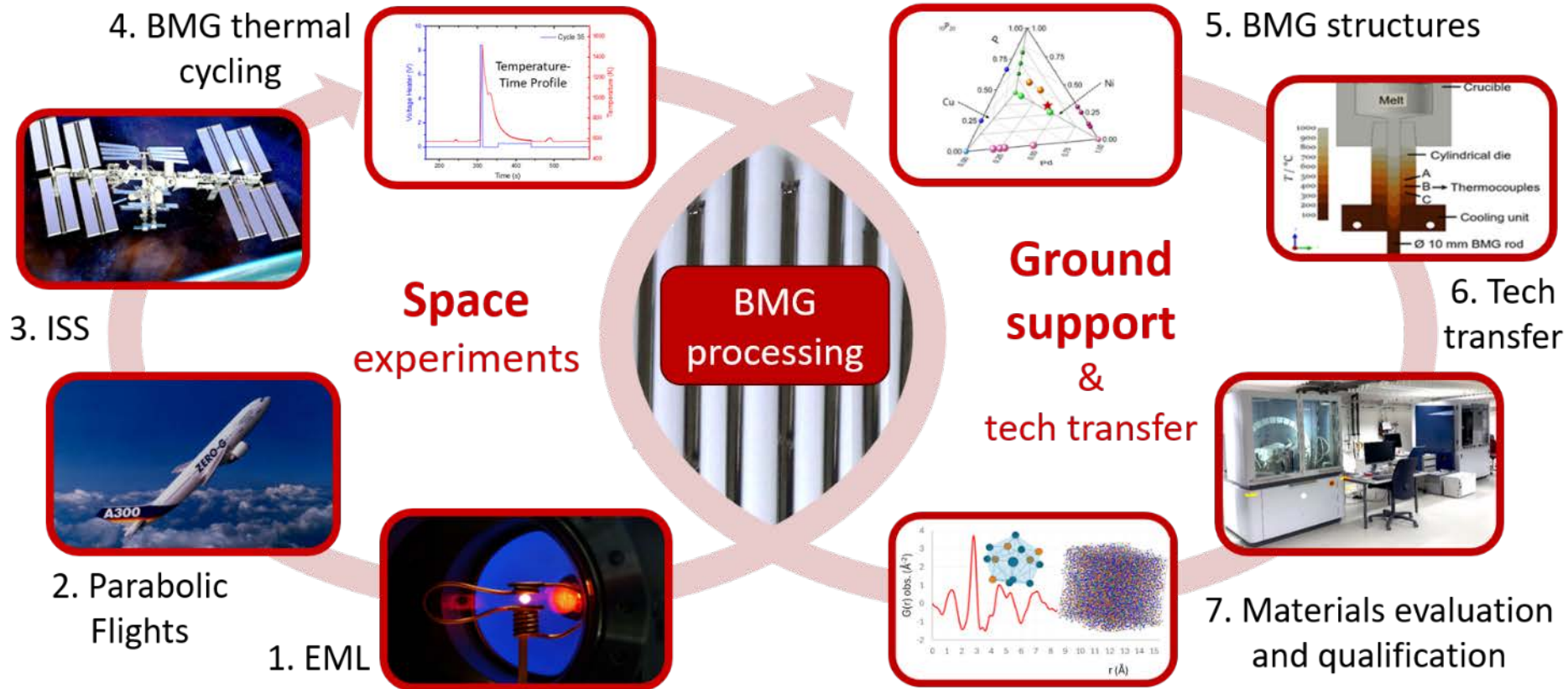


Study of space impact on BMGs:
temperature, cosmic radiation, microgravity

Thermophysical properties:
surface tension, viscosity

- S. Thomä et al, Journal of Materials Research and Technology, **2024**, 33, 6207-6215. DOI.org/10.1016/j.jmrt.2024.10.236.
- D. Terebenec et al. , NPJ Microgravity, **2026**, 12:26, 1-10. <https://doi.org/10.1038/s41526-026-00572-6>.
- D. Terebenec et al., Journal of Materials Research and Technology, **2026**, 43, 2788-2800, <https://doi.org/10.1016/j.jmrt.2026.06.151>.

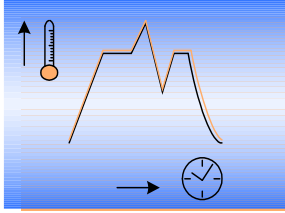
Supporting materials processing in industry: Complementarity of space and ground experiments



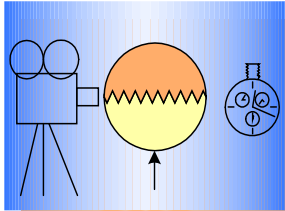
Electro-Magnetic Levitation Solidification



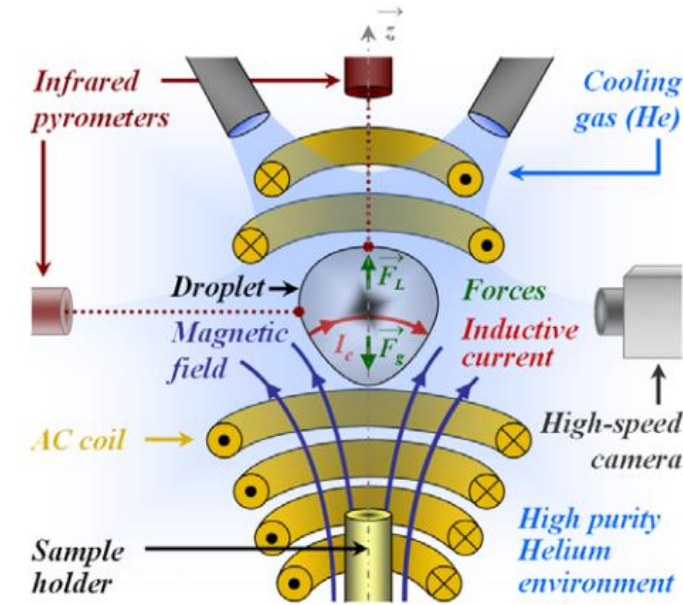
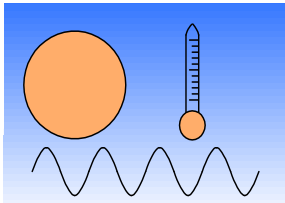
Cooling



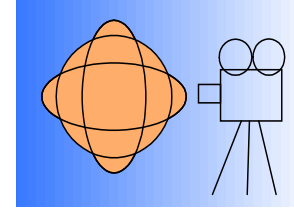
Nucleation and Growth



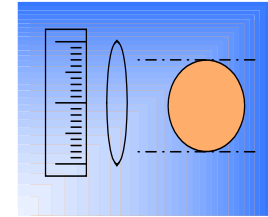
Calorimetry



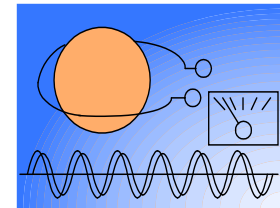
Viscosity / Surface Tension



Density

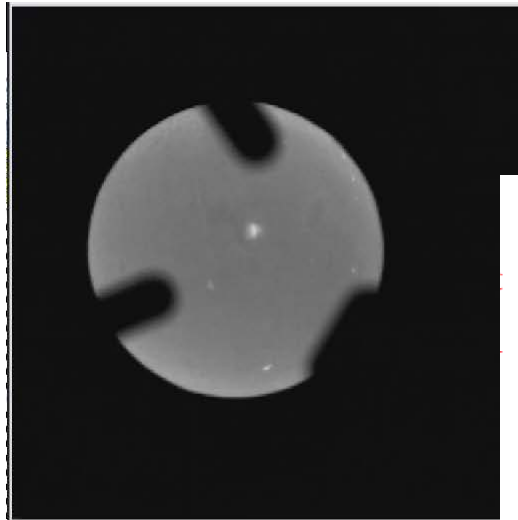


Electric Resistivity

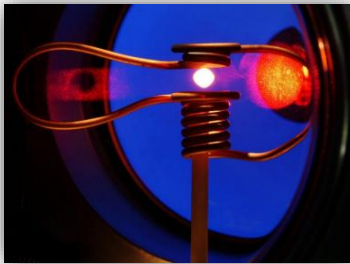
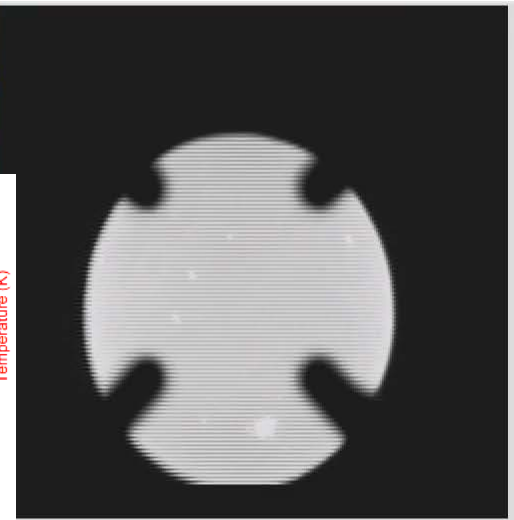
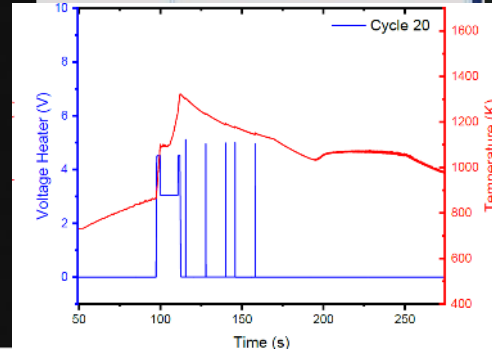


ISS experiments provide unique experimental basis to support the modeling effort which is essential for materials processing and fundamental understanding of solidification.

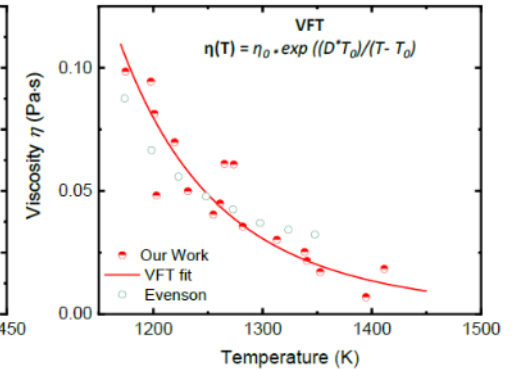
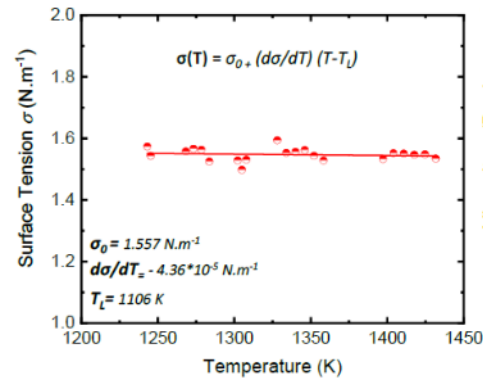
ISS experiments in μ -gravity



Oscillation
drop method



D. Terebenec et al., NPJ Microgravity, **2026**, 12:26, 1-10. <https://doi.org/10.1038/s41526-026-00572-6>.



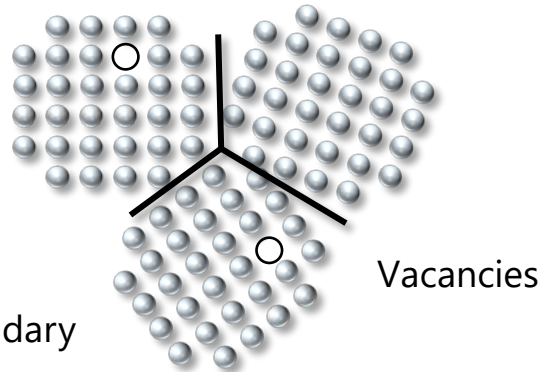
Why are metallic glasses interesting ?



Bulk metallic glasses (BMG) are amorphous (i.e. non-crystalline) metals with outstanding properties compared to conventional metals:

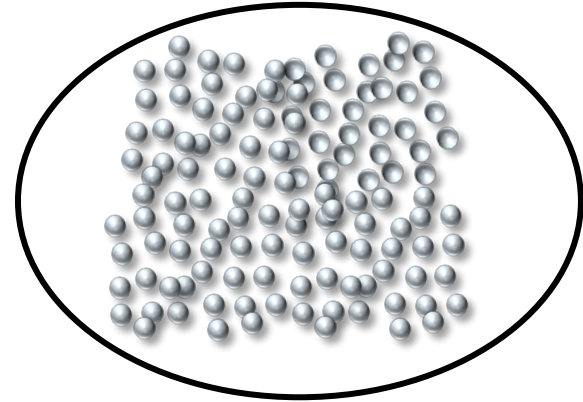
Conventional Metals

Crystalline / long-range ordering



Metallic glasses

Amorphous / absence of long-range ordering



- High mechanical strength with outstanding elasticity.
- Increased wear, scratch and corrosion resistance.
- Operation in extreme conditions down to -150°C .
- Can be produced with extremely flat (mirror-like) surfaces.

Applications for metallic glasses



COLDArm design
of a lunar lander



Credits: NASA, Caltech

Flexible BMG
components



Credits: PX Services

Watch parts



Credits: PX Services

Components used in
BMG planetary gearbox



Credits: NASA

Coatings for protection



Credits: PX

AM implants



Credits: Heraeus, Trumpf

Thin films



Flexible substrates

μ-Gravity experiments on ISS: metallic glasses



Experiments: parabolic flights & ISS



AIRBUS

ISS-Batch #1

Batch #2

Batch #3

Batch #4

Batch #5

2006-2014

Project follower as
an observer

2015-2018

ESA-PRODEX:
THERMOPROP-I

2019-2022

ESA-PRODEX:
THERMOPROP-II

2023-2026

ESA-PRODEX:
THERMOPROP-III

2027-2030

ESA-PRODEX
THERMOLAB

Experiments: Empa

PIXGROUP
INNOVATIVE SOLUTIONS PROVIDER

oerlikon



Alex
Dommann



Antonia
Neels



Ruggero
Frison



Aurelio
Borzi



Robert
Zboray



Sabrina
Thomä

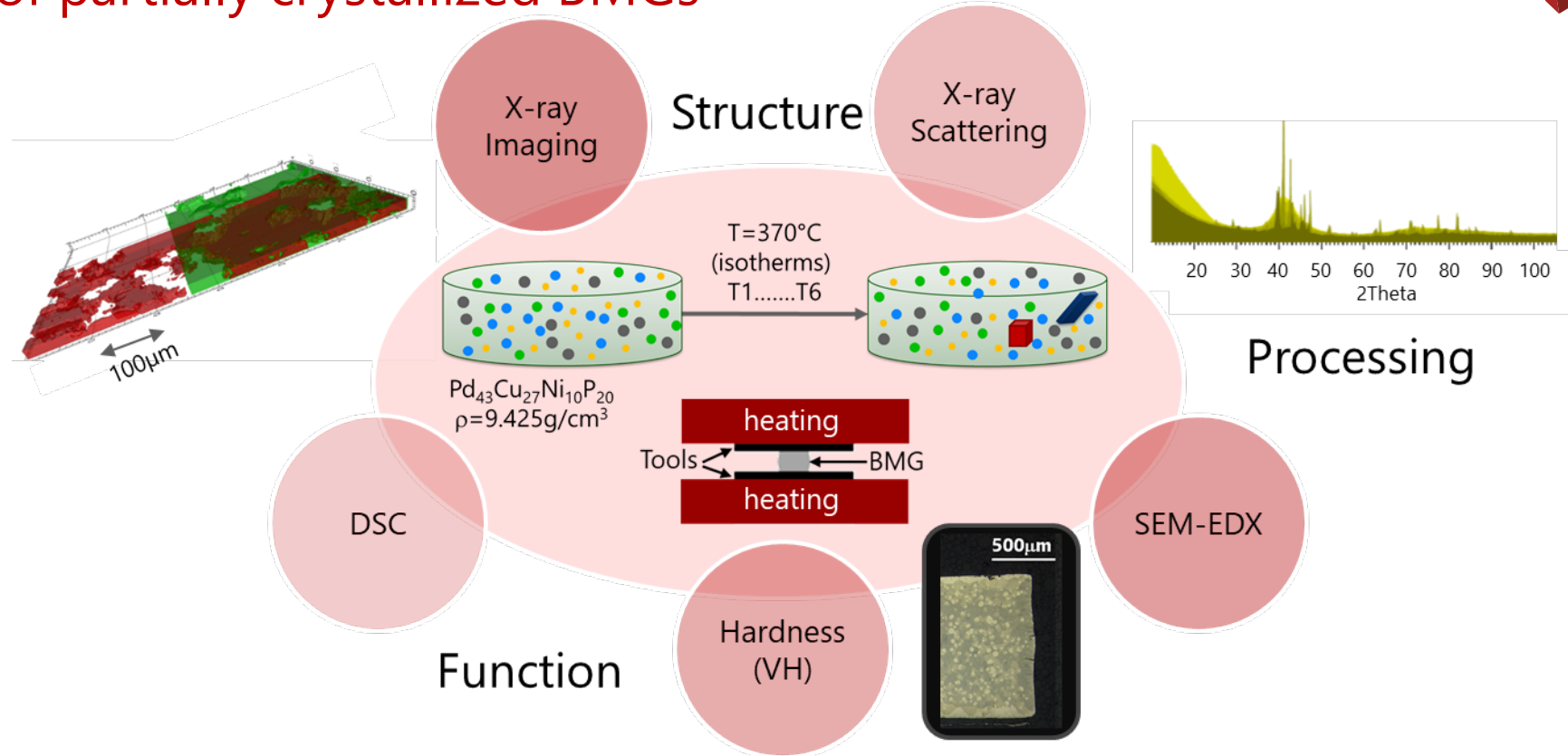


Damien
Terebenec

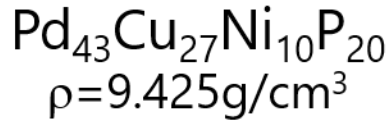
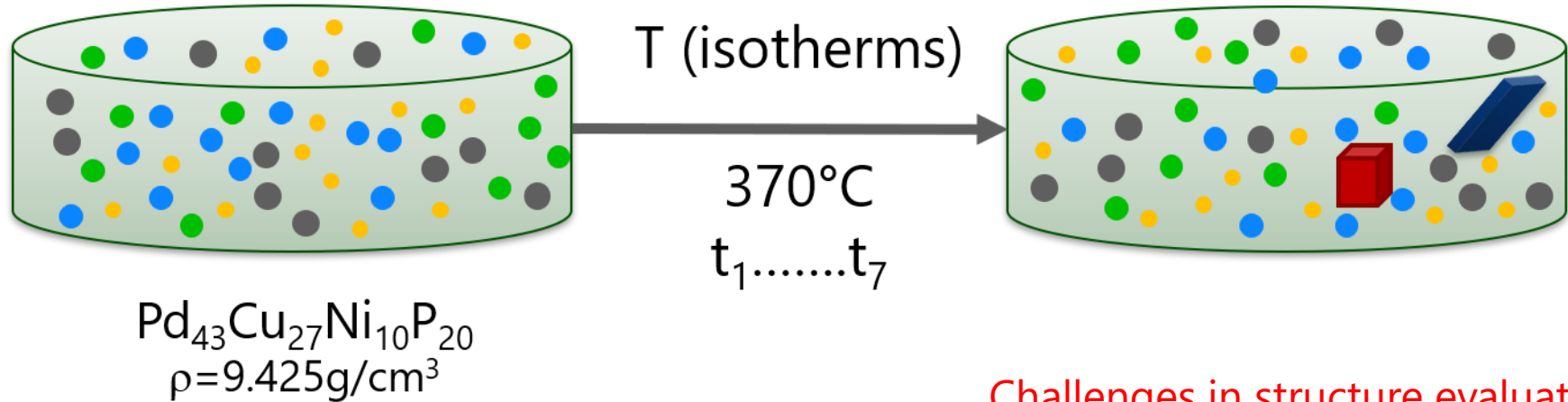


Fabio
Manzoni

Multiscale and multiparametric study of partially crystallized BMGs



Enhancing physical (mechanical, thermal) BMGs properties: partial crystallization in an amorphous matrix



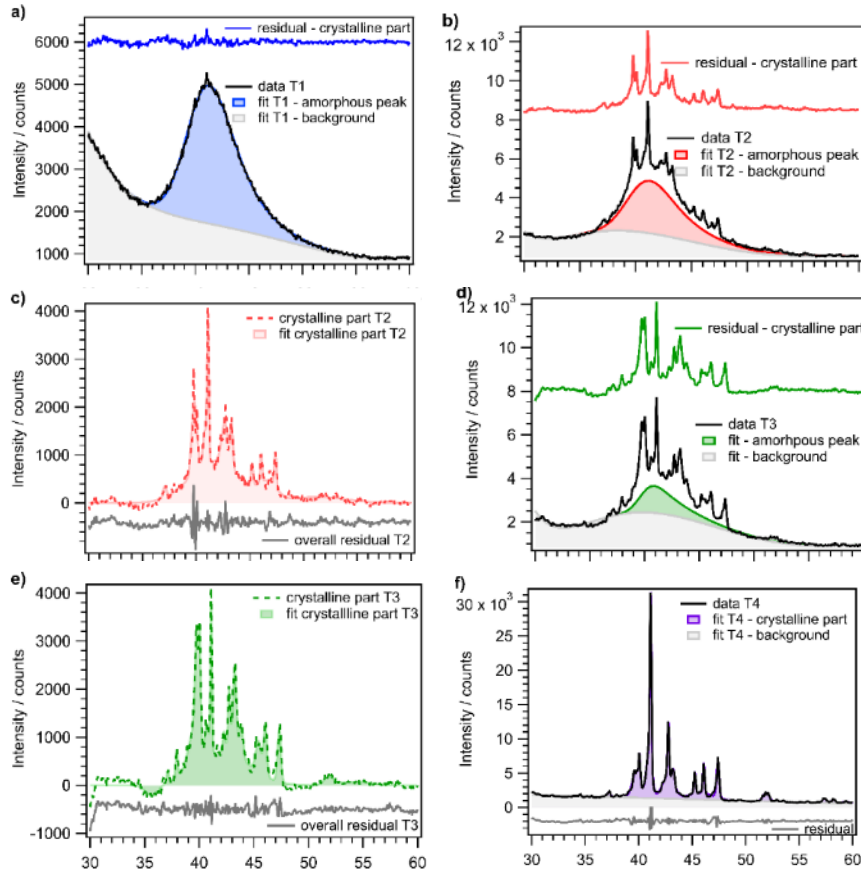
Challenges in structure evaluation

- Phase separation
- Multi phase systems
- Metastable phases
- Preferred orientation
- Nano-micro-crystals
 - Crystallinity
- Strain & relaxation

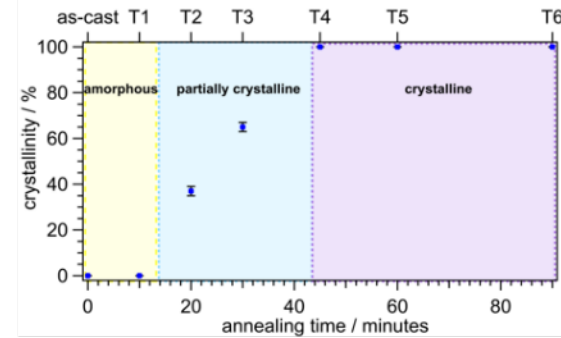
- Controlled crystallization:
 - In-situ composites for improved mechanical properties of the BMG parts.
 - How can we influence ductility or shock resistance ?

Crystallization, phase separation and integrity:

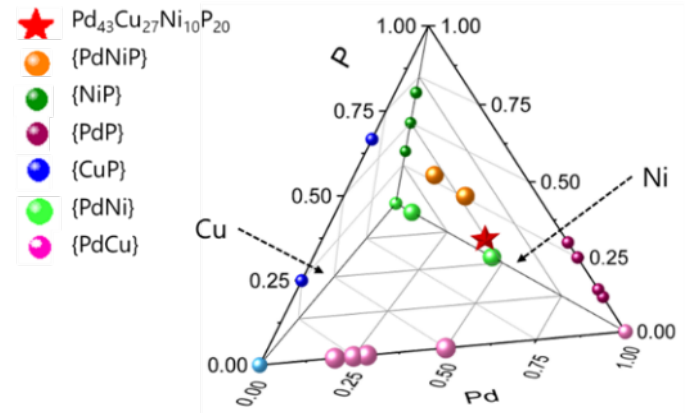
Quantification of crystallinity by advanced modelling



Percentage of crystallinity vs annealing time



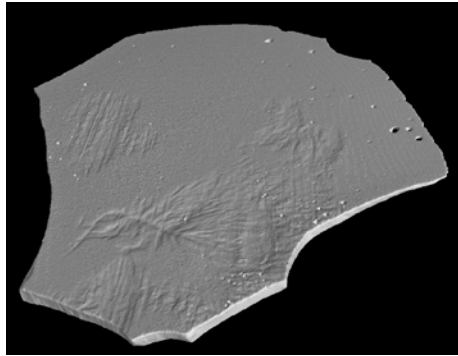
Phase diagram



Morphology investigation: density segmentation and coupling with structural densities

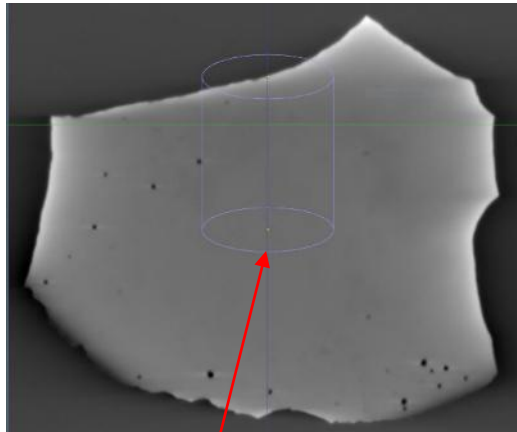


- X-CT
- 3D rendering of the sample: 3D defect analysis
- Partial crystallization in a surrounding matrix?

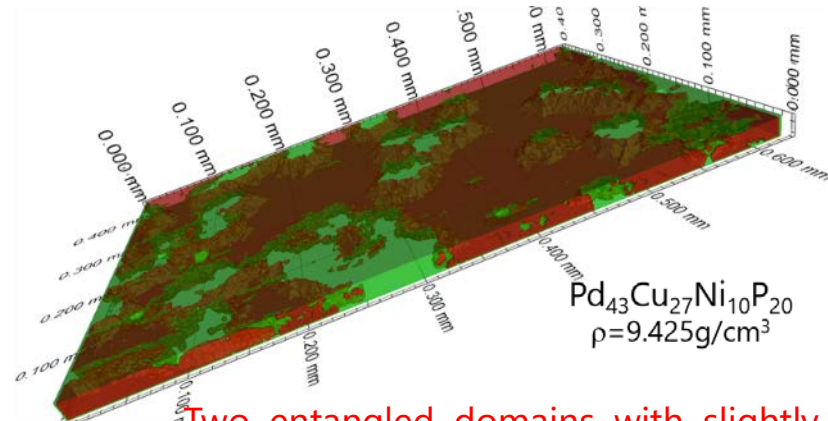
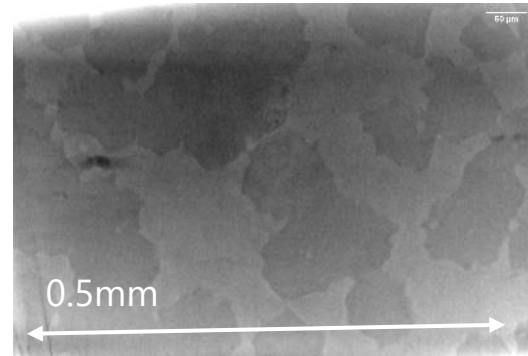


There are some holes, some surface defects (open porosity) and some real defects (closed porosity).

Propagation-based phase contrast local nanoCT



ROI for local CT **Resolution:**
Voxel size local CT: 0.34 μm
Voxel size global CT: 0.96 μm



Two entangled domains with slightly different densities: 57% higher density (metal solid solutions) & 43% lower density (metal phosphides).

Reliable manufacturing



Manual casting of rods FAB-1



Continues casting of rods FAB-2



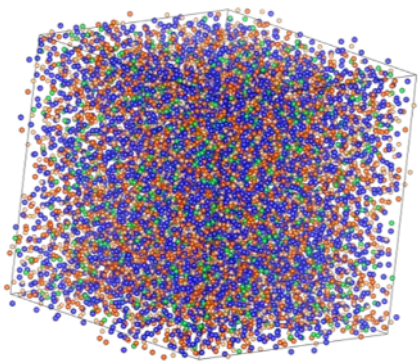
Thermoforming FAB-3



Granulation FAB-4



FAB-1 and FAB-2: fitting and Voronoi polyhedra



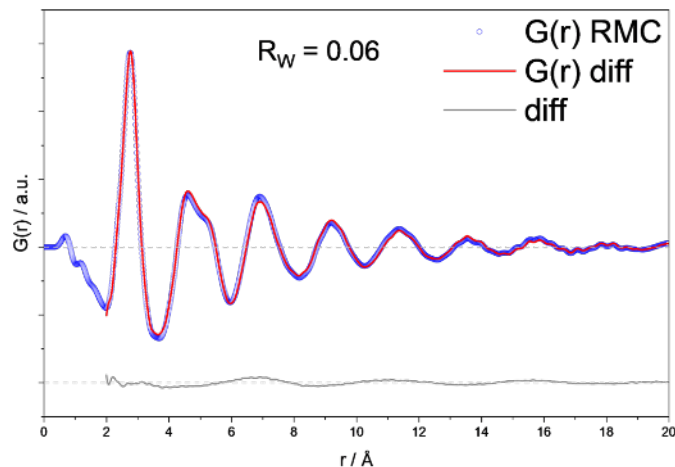
PDF data analysis:

Reverse Monte
Carlo Simulations

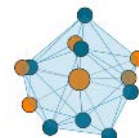
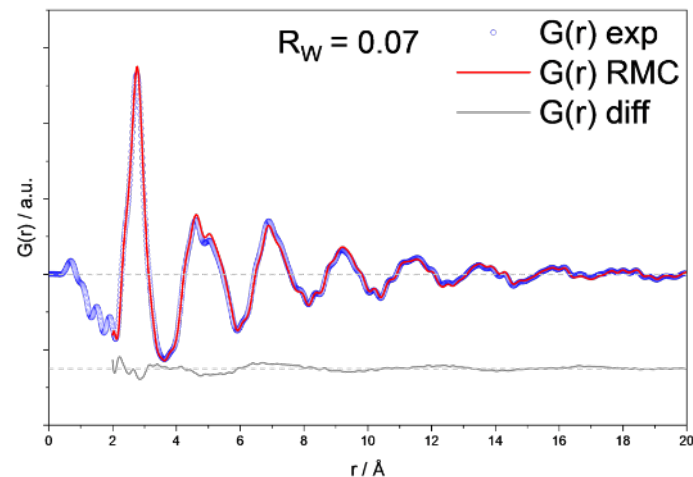
→ Big box modeling



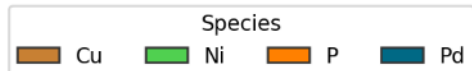
FAB-1



FAB-2



- Evaluation of coordination numbers, atomic volume
- Findings correlate with results from mechanical tests



Materials lifted up to space



NASA's SpaceX 31st Resupply Mission to Launch Experiments to Station



Flight to ISS: November 2024
Flight back to earth: April 2026



2 samples fixed outside ISS: Dec. 2024 – Dec. 2025

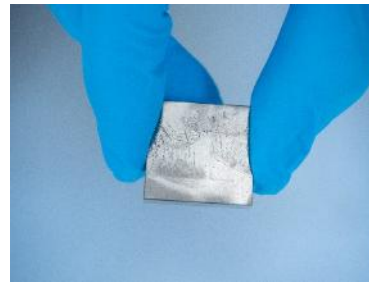
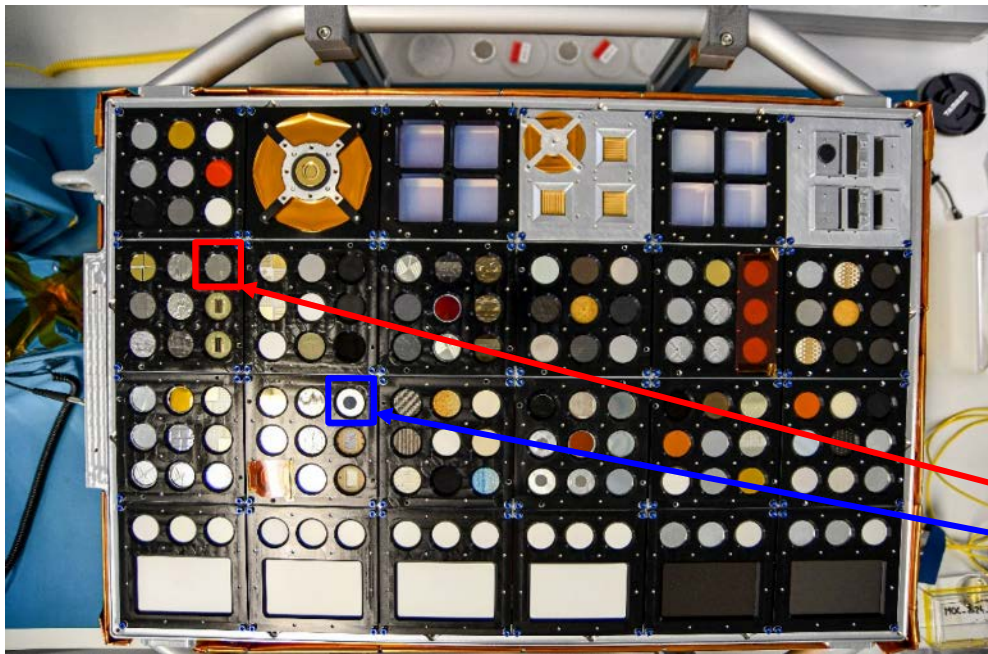
ESA selected and tested 45 samples, from 15 different research institutes throughout Europe, now exposed to outer space in the Euro Material Ageing facility from CNES.

https://www.esa.int/ESA_Multimedia/Images/2025/01/In_a_materials_world

Sample download to earth



- Samples received 15th of September 2026



Ground sample: Pd-BMG

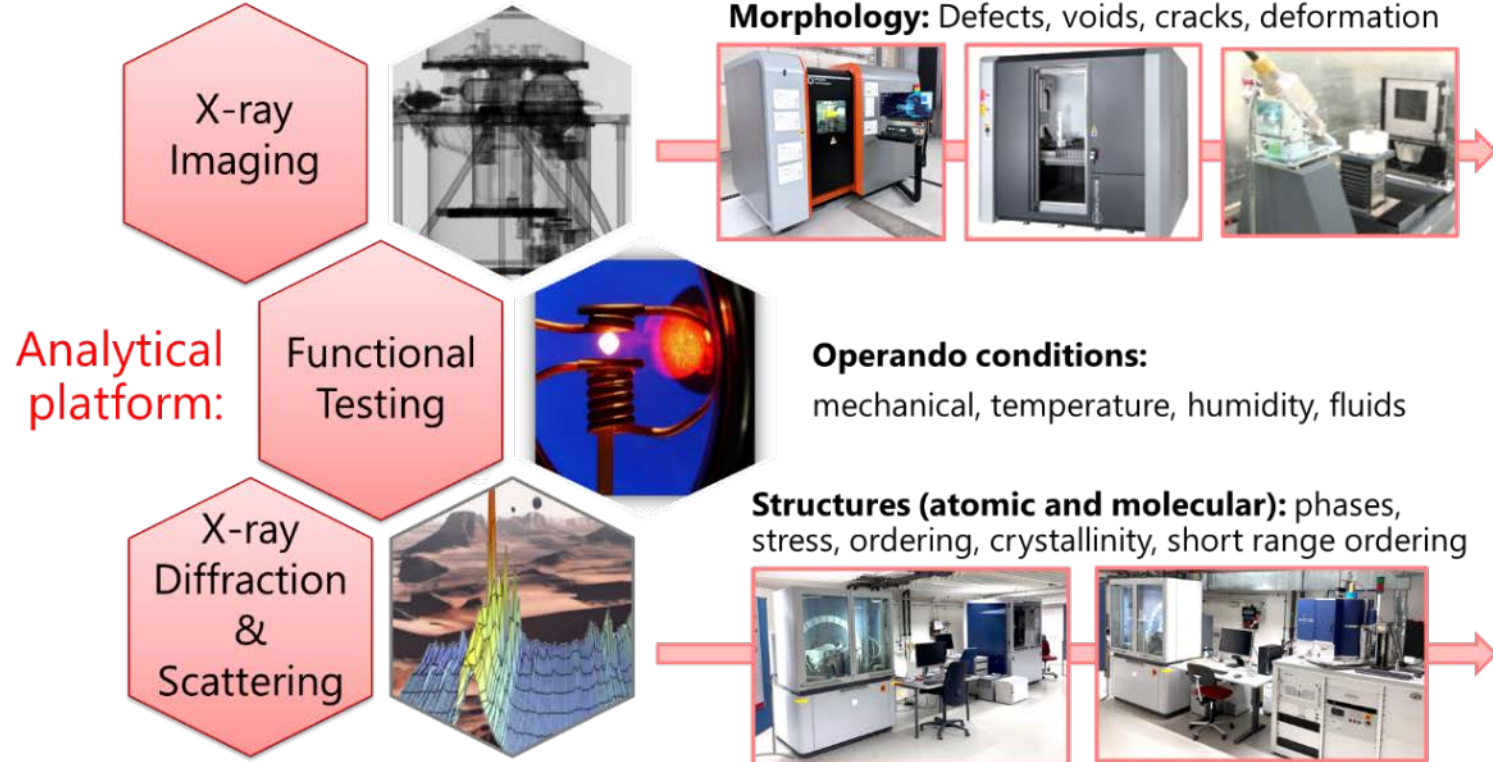


Sample mounting
outside ISS

- 1) the sample with the red frame, sample holder 11, is Pd-BMG, and
- 2) the sample which is in the blue frame, sample holder 10 is Si-NWRs.

- Defect analysis starts now for studying the impact of the space environment on the new materials.

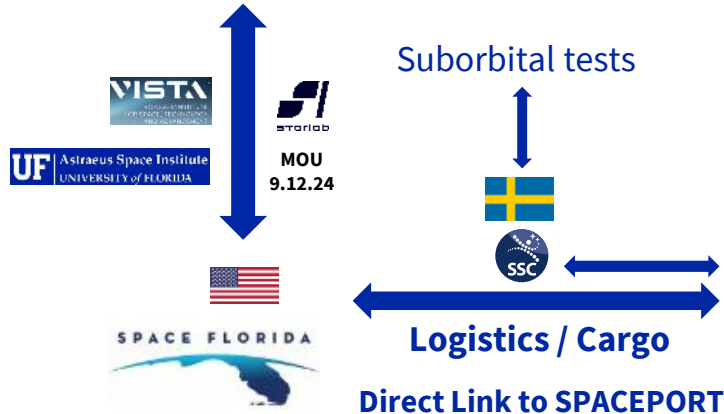
Summary: Established new analytical platform at Empa: X-ray based and non-destructive



Context: Center for Space and Aviation Switzerland and Liechtenstein (CSA)

Partners

SPACE STATIONS (R & D & production)



Location

R&D AND Trade Hub



Switzerland Innovation Park Zurich

Competences

Center for Space and Aviation Switzerland and Liechtenstein



Enabling a successful launch of the new space economy: Space medicine, material science & Engineering including very close links to industry.

Acknowledgements

- The Empa X-ray team
- Prof. Roland Logé, EPFL
- Dr. Silke Prades-Rödel, PX Services
- Swiss Space Office SSO



armasuisse



Contact: antonia.neels@empa.ch

