Advanced Manufacturing Techniques for the Big Science

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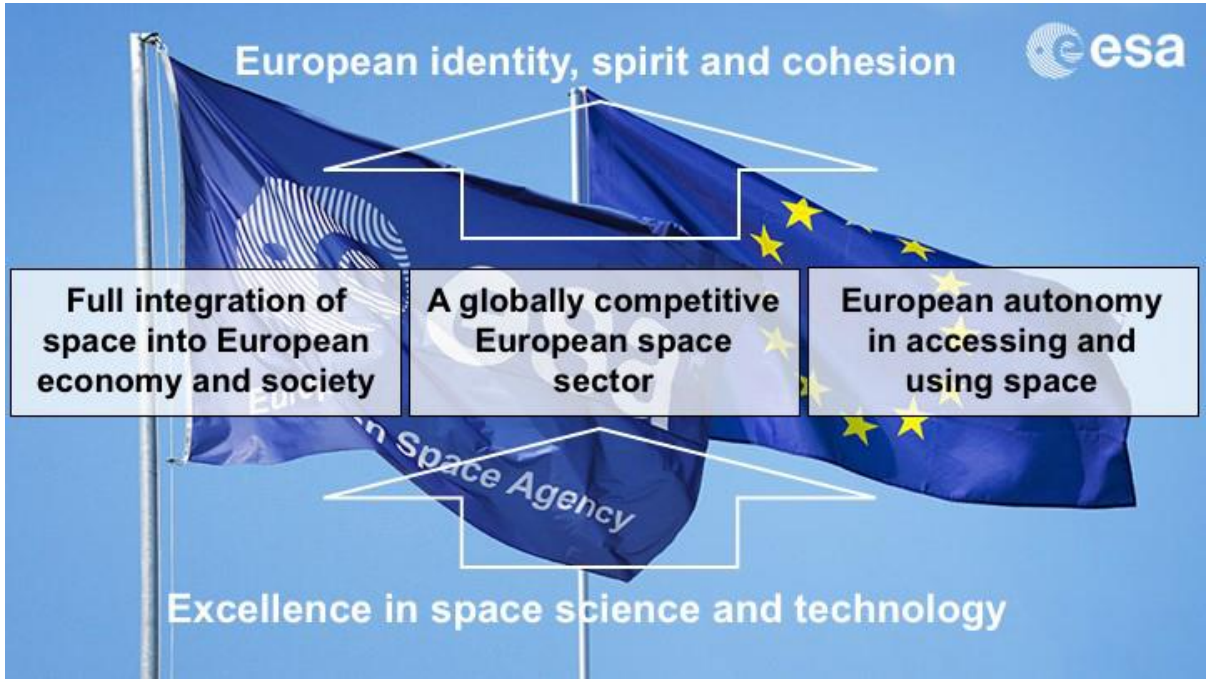
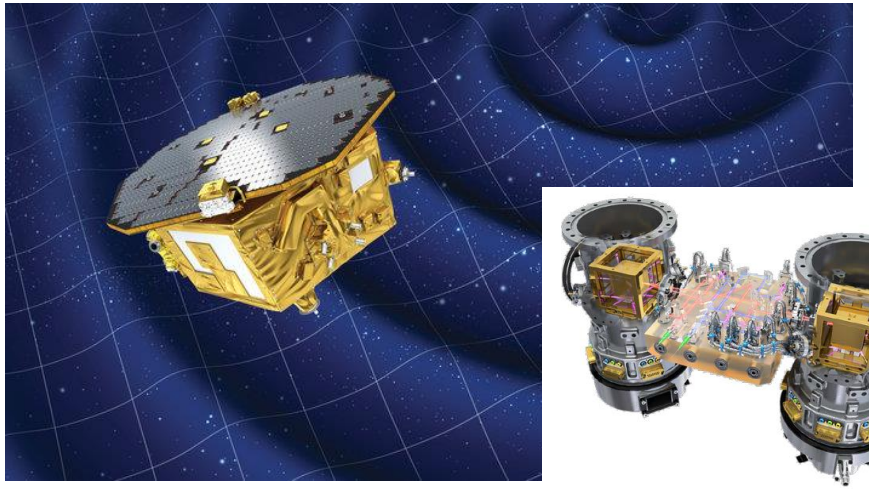
BSBF 2022, 4-7 October 2022

Technology Strategy

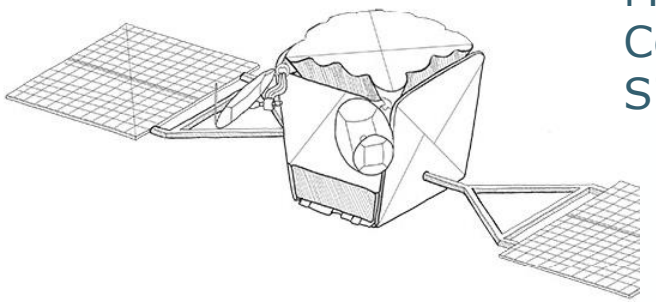




Unique science missions
Pushing frontiers

Technologies for full spectrum of activities

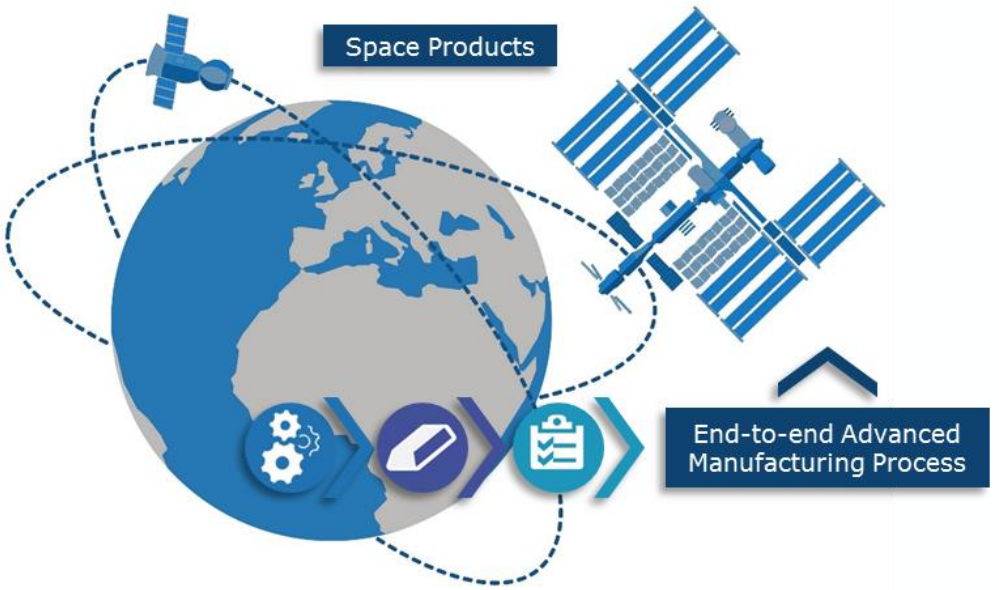
Mass market
Cost-driven
Simplification



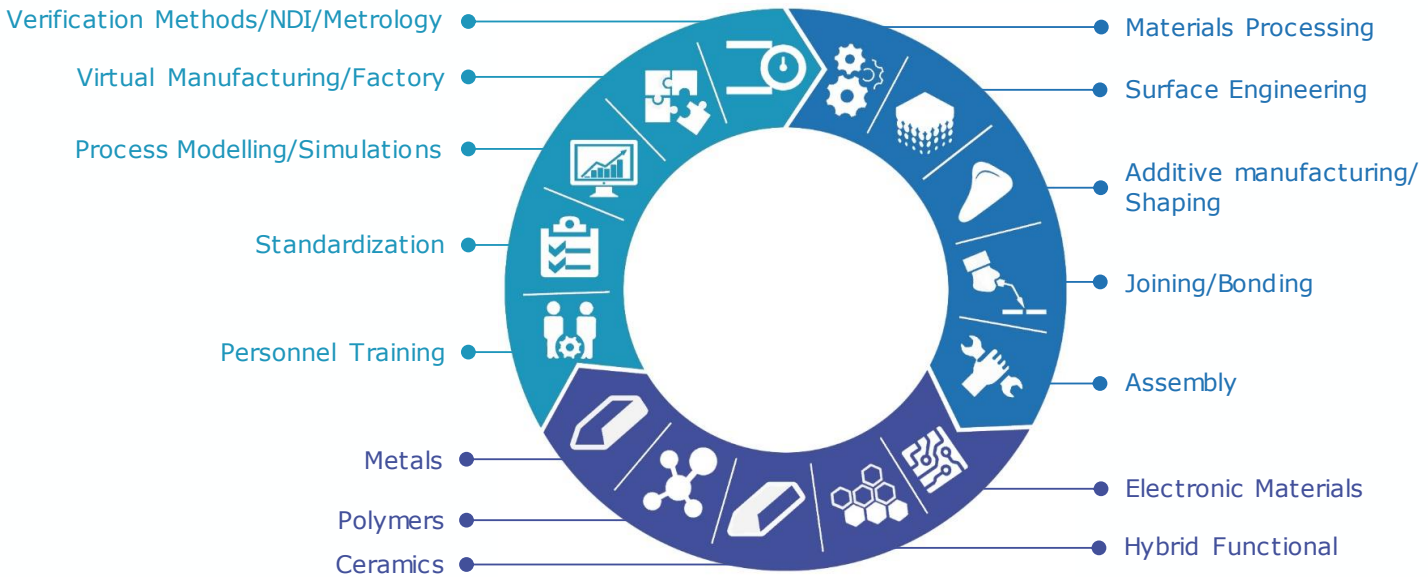
Advanced Manufacturing - Objectives

- To create new high performance Space products by actively reducing the limitations imposed by the traditional manufacturing processes/concepts
- Profit of the ideal opportunities in Europe to spin-in the digital manufacturing technologies and Industry 4.0 to space
- Identify and implement new manufacturing technologies for space applications enabling:

  - Design freedom
  - Performance improvement
  - Costs reduction
  - Lead time reduction
    (from concept to manufacturing)



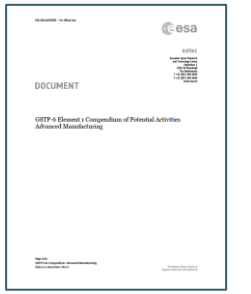
Advanced Manufacturing – Areas of Interest



Major funding contribution through GSTP

1st compendium released end 2015

http://emits.sso.esa.int/emits-doc/ESTEC/News/GSTP6E1-AdvancedManufacturing-Compendium-Rev2.pdf



2nd compendium released end 2019

http://emits.sso.esa.int/emits-doc/ESTEC/News/GSTPAMCompedium2019.pdf

Activities implemented over a wide range of ESA funding schemes and engineering disciplines

- Co-funded research, early technology demonstration
- TDE, GSTP, Artes, FLPP, *etc.*

Harmonisation Roadmap on Additive Manufacturing for Space

- Roadmap proposes about 30 types of parts (AIM A)
- Roadmap proposes technology developments (Aims B to F)
- **Roadmap endorsed by the IPC**

Aim B: Design

Aim C: Material Supply

Aim D: Processing

Aim E: Post Processing

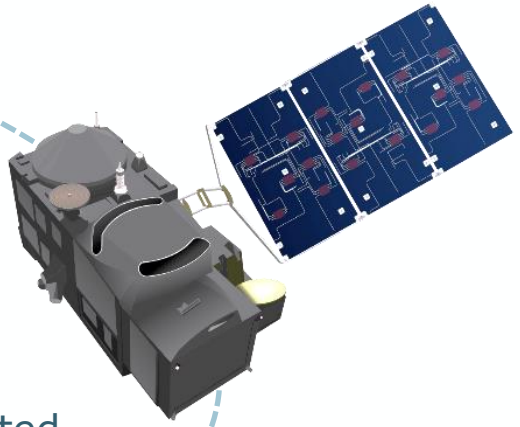
Aim F: Qualification

Aim G: Standardization

Aim A:

Originally in 2015:

- More than **700 experts**
- **26 countries** represented
- **390 companies** represented
- **62 new members** joined the roadmap space community

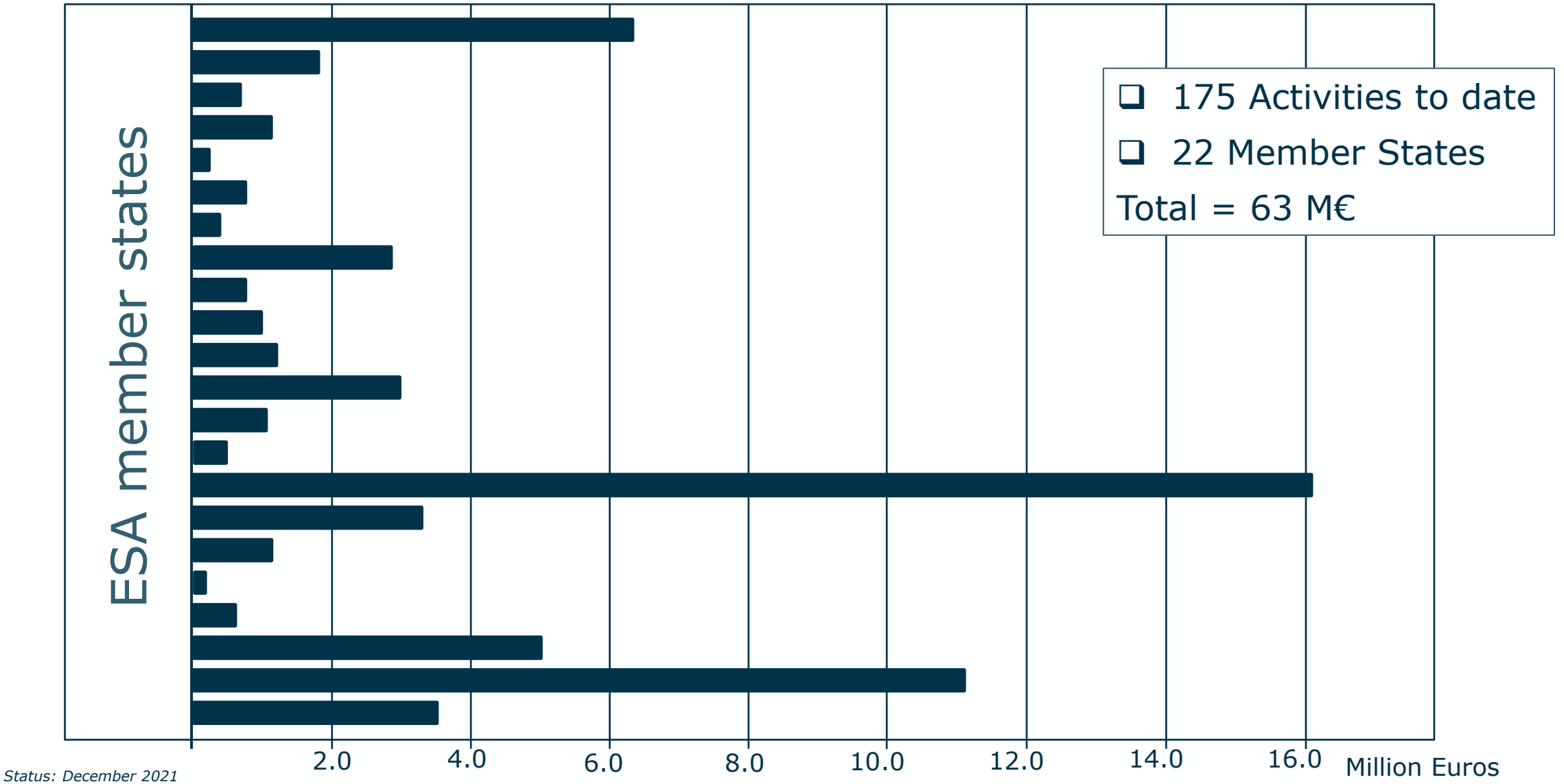


End-to-end AM process

2nd Roadmap revision ongoing

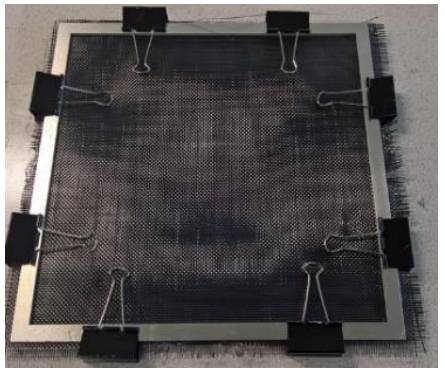
Image source: dragoart.com

ESA Funded Activities in Advanced Manufacturing

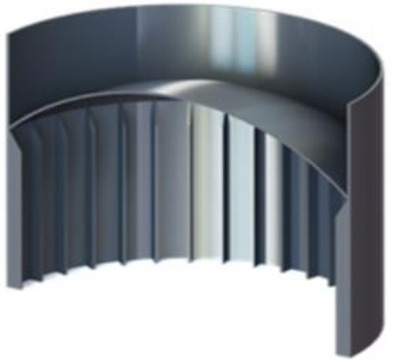


Status: December 2021

Example activities after

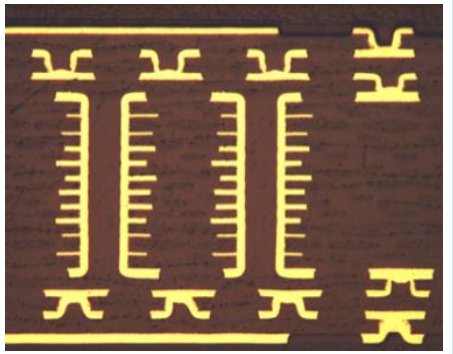


Out of Autoclave Processing

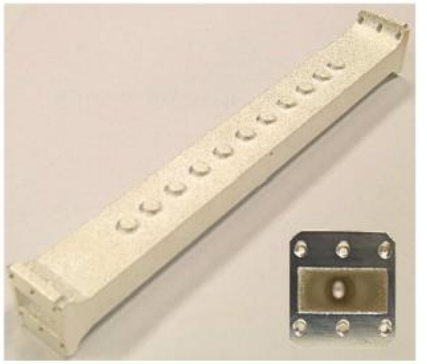


Advanced Forming Technologies

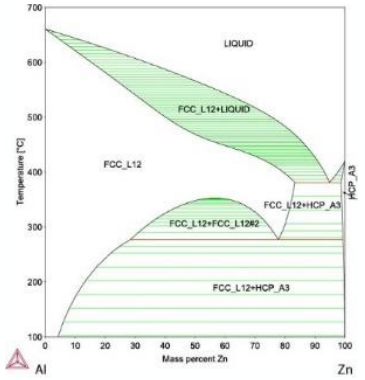
3D Honeycomb for Curved Structures



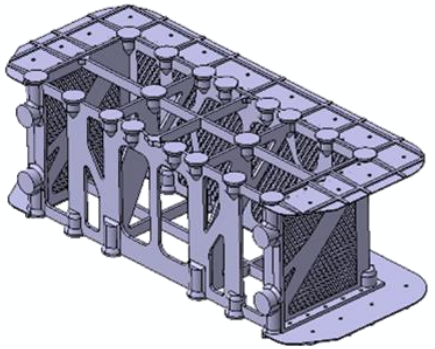
High Density PCB Assemblies



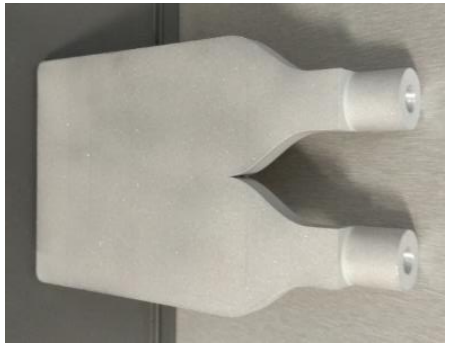
Single Part Wave Guide Filters



High Strength Al Alloys for Additive

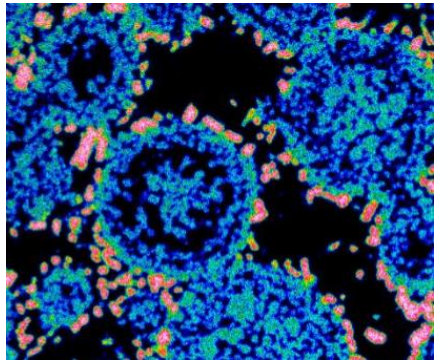


Primary Structures for Additive



Embedded Thermal Functions

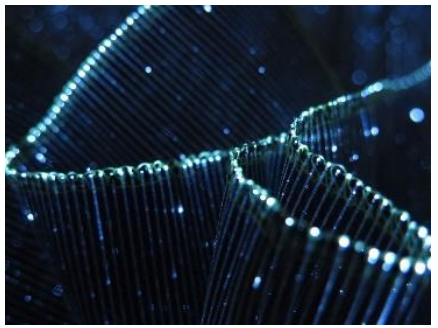
Compliant Mechanisms for Additive



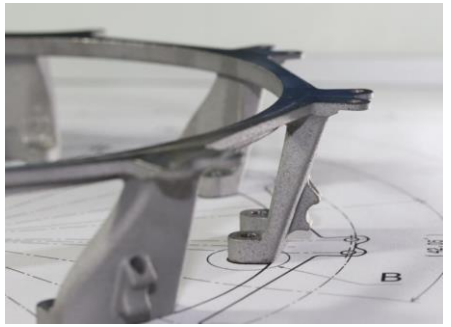
PM High Wear Resistance Alloys

Example activities after

Extended Pot Life Resins



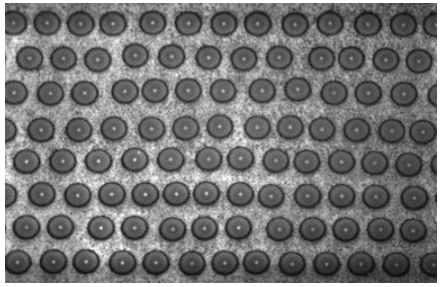
Integrated Optical Fibres



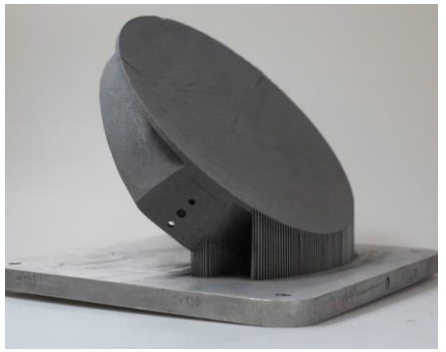
Design Methods for AM

Low Density Areal Mirrors

Large Optical Bench

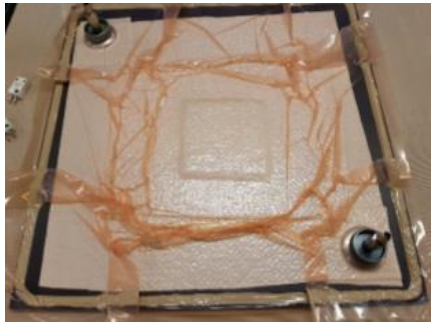


Filament Winding of TISIC

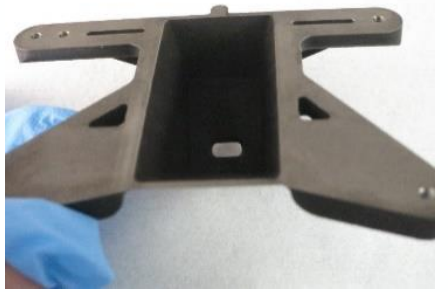


Assessing The Use of AM

Thin Ply Composite Structures



Curing On Demand



CoBlast Thermal Coatings

Smart Manufacturing → 2nd compendium

Data Acquisition
- Embedded sensors
- Test data
- Process monitoring

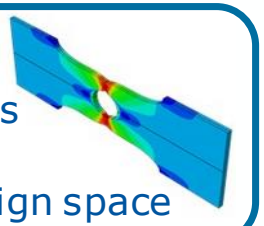
Tool Development
- Metallurgical Models
- Through Process Models
- Neural Networks

Qualification
- Tailored Approach
- Flying prototypes
- COTS / Open Source

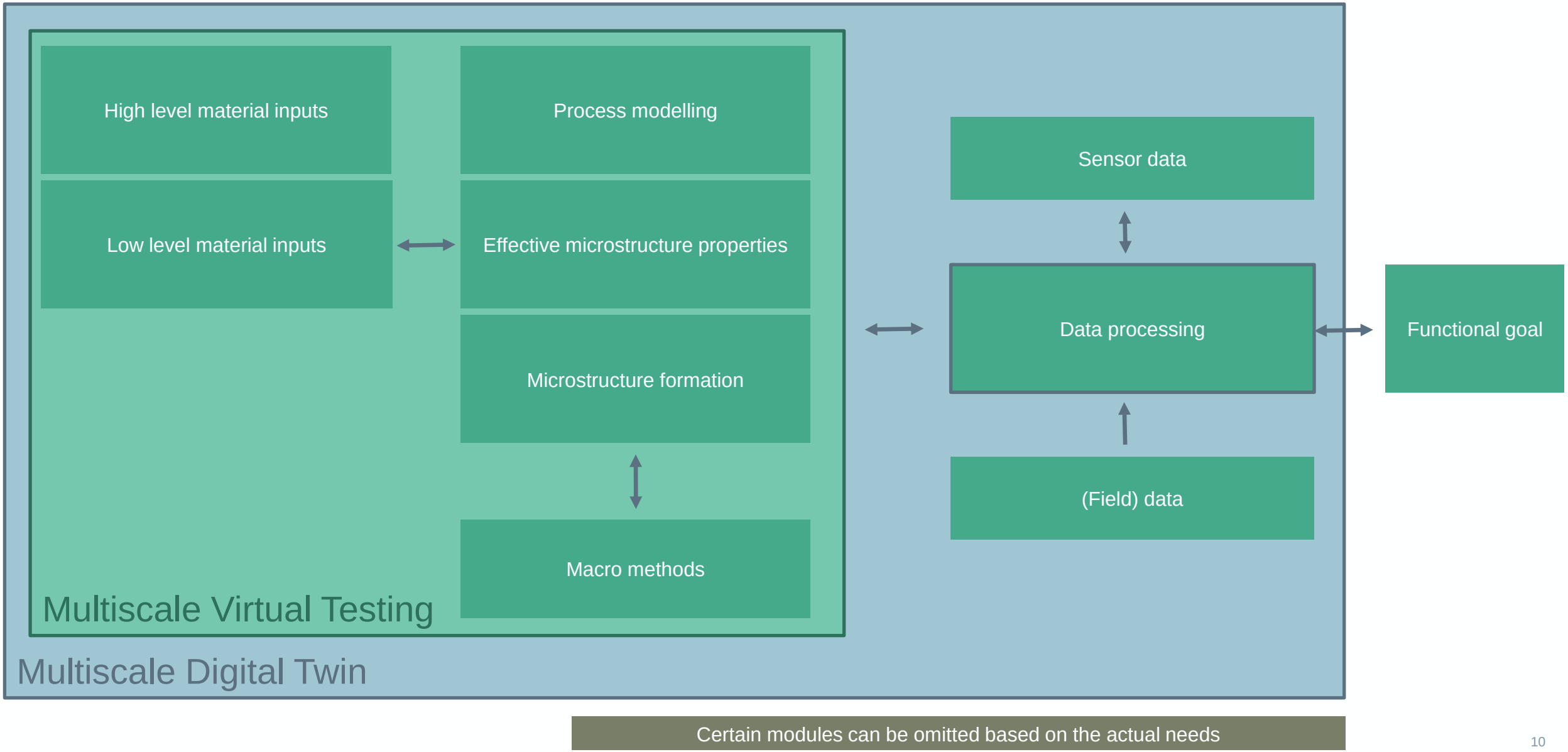
Data Manipulation
- Intelligent process control
- Machine Learning / AI
- Virtual Twins

Standardisation
- ESA to drive standardization
- Process Monitoring/Control
- Cyber Security

Virtual Testing
- Reduce the number of tests
- Explore more cases
- Change the traditional design space



Virtual Testing and Digital Twins – modularity

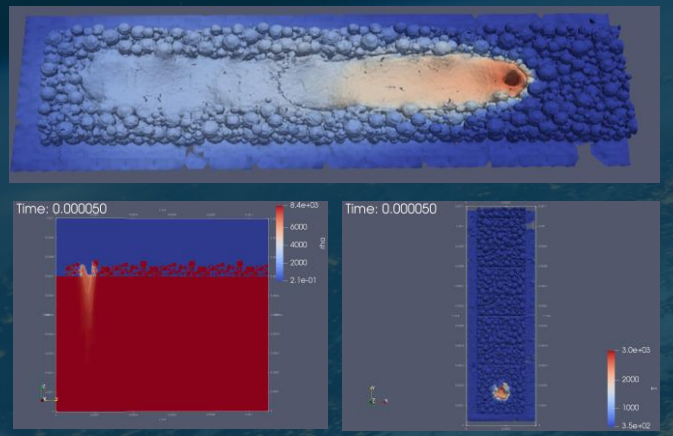


Certain modules can be omitted based on the actual needs

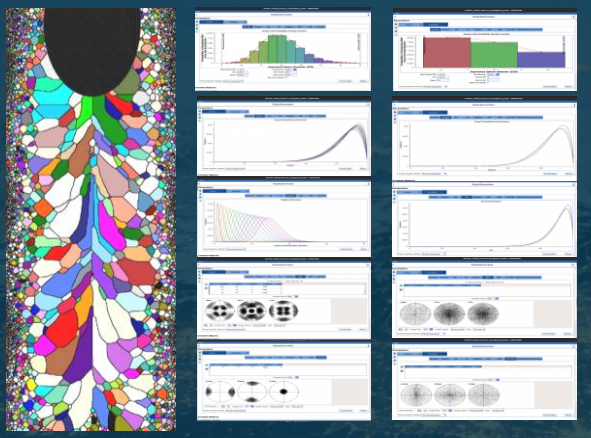
V&V for ICME for SLM (example)

Physics based modelling of the process ⟷ Microstructure modelling ⟷ Effective properties of the part

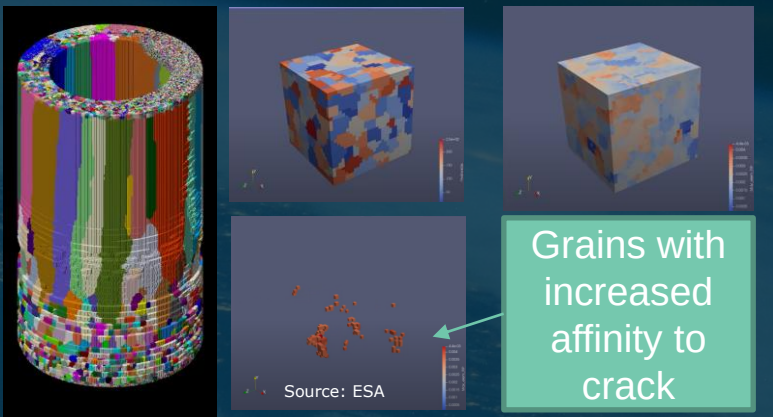
simulation



Multi-phase multi-physics process description Source: ESA

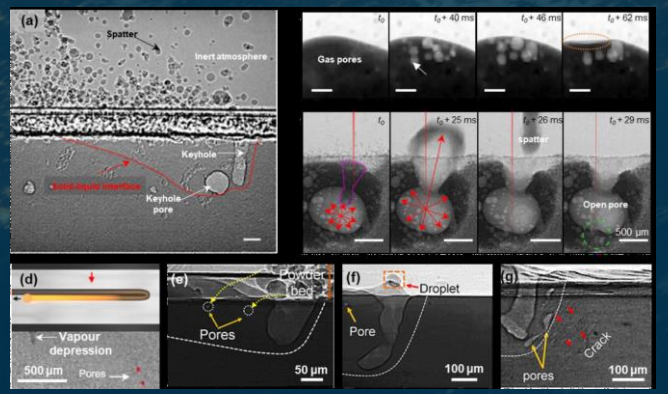


Numerical and statistical description of microstructures (sRVE) T. M. Rodgers, J. A. Mitchell, and V. Tikare, Modelling and Simulation in Materials Science and Engineering, 25, 064006 (2017)



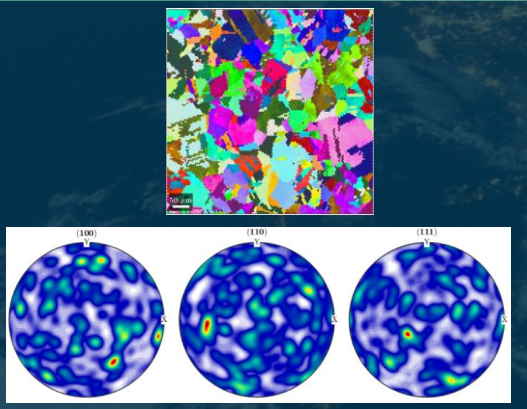
Micro-scale elasto-plasticity and fatigue mechanics – CP / EVD FIP T. M. Rodgers, J. D. Madison, V. Tikare, Computational Materials Science 135, 78-89 (2017)

V&V

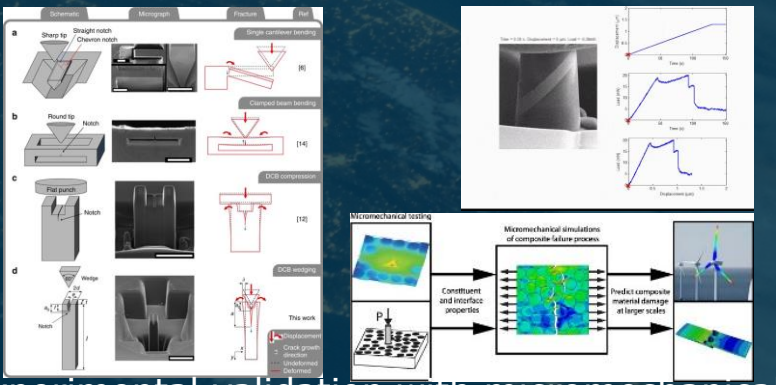


Numerical software experimental validation with S-XCT

Leung C. L. A., Marussi S., Atwood R. C., Towrie M., Withers P. J. & Lee P. D. In situ X-ray imaging of defect and molten pool dynamics in laser additive manufacturing. Nat. Commun. 9, 1355 (2018). DOI: 10.1038/s41467-018-03734-7



Experimental validation with EBSD and S-XCT https://mtex-toolbox.github.io/



Experimental validation with micromechanical testing

M. Hardiman et al./Composite Structures 180 (2017) 782–798
Sernicola, G., Giovannini, T., Patel, P. et al. In situ stable crack growth at the micron scale. Nat Commun 8, 108 (2017).
https://alemnis.com/micropillar-compression/

Advanced Manufacturing – Industrial Opportunities at ESA

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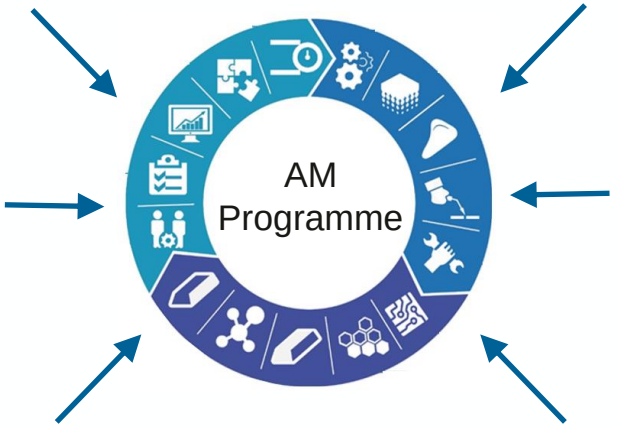
Technology Programme - Stakeholders

Mission needs & requirements

ESA Technology Roadmaps

Space Primes

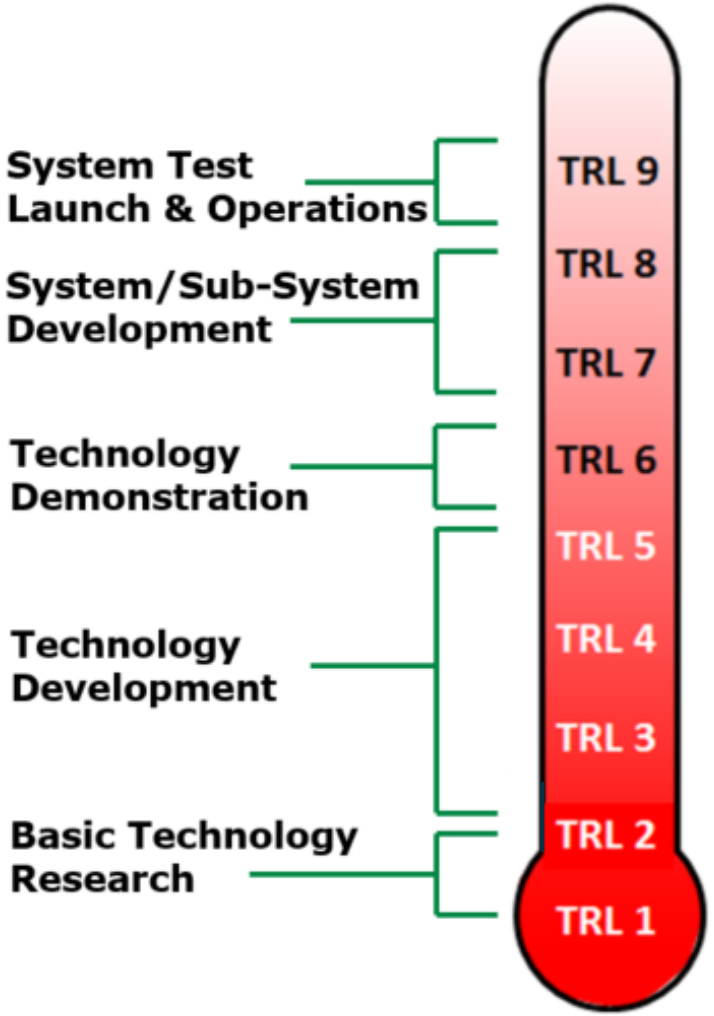


European Space Community (including SMEs, research institutes, academia, etc.)

Key Tier 1 suppliers

Key technology partners

ESA Technology – Funding Streams



Flight

Industrial qualification

General Support Technology Programme

- Optional Programme for ESA member states

Technology Development Element

Discovery

- Mandatory for all member states
- Entire spectrum of technical disciplines

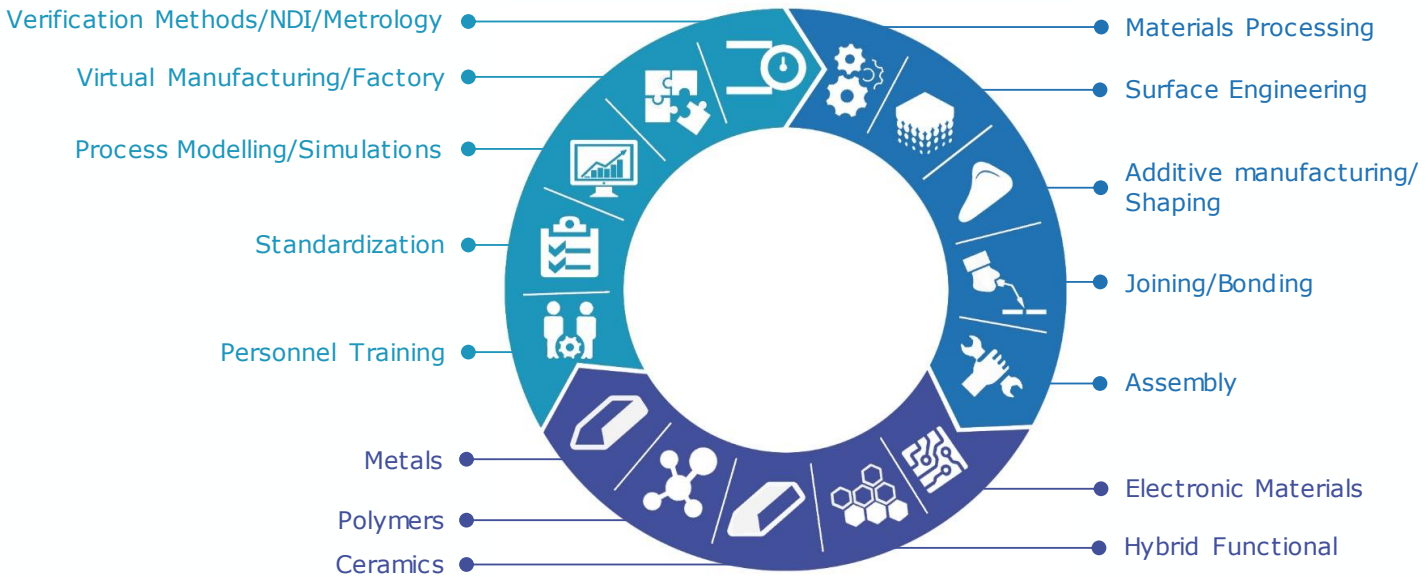
ARTES Programme

- Dedicated to Telecoms

FLPP Programme

- Dedicated to Launchers

Advanced Manufacturing – Areas of Interest



Activities implemented over a wide range of ESA funding schemes and engineering disciplines

- Co-funded research, early technology demonstration
- TDE, GSTP, Artes, FLPP, *etc.*

Major funding contribution through GSTP

1st compendium released end 2015

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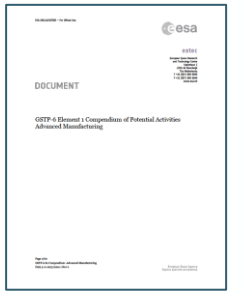
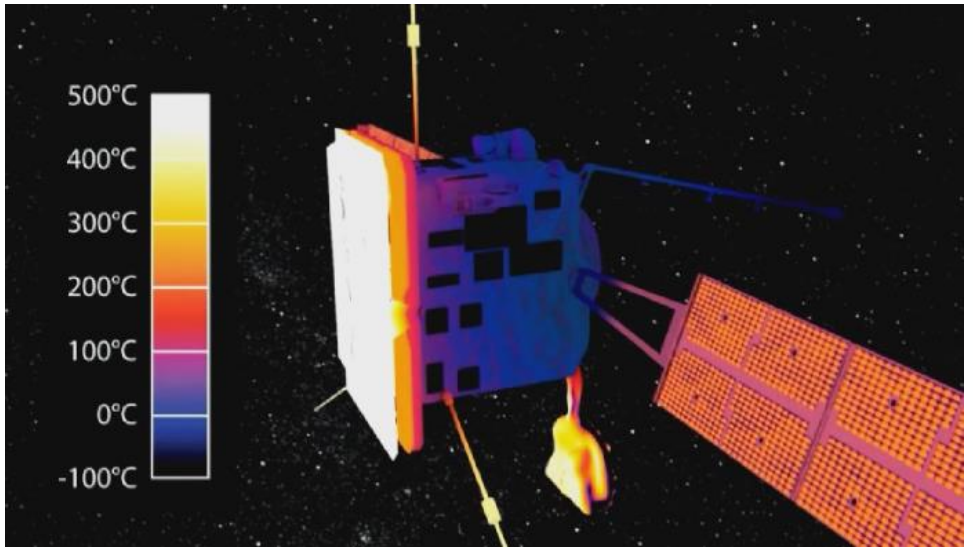


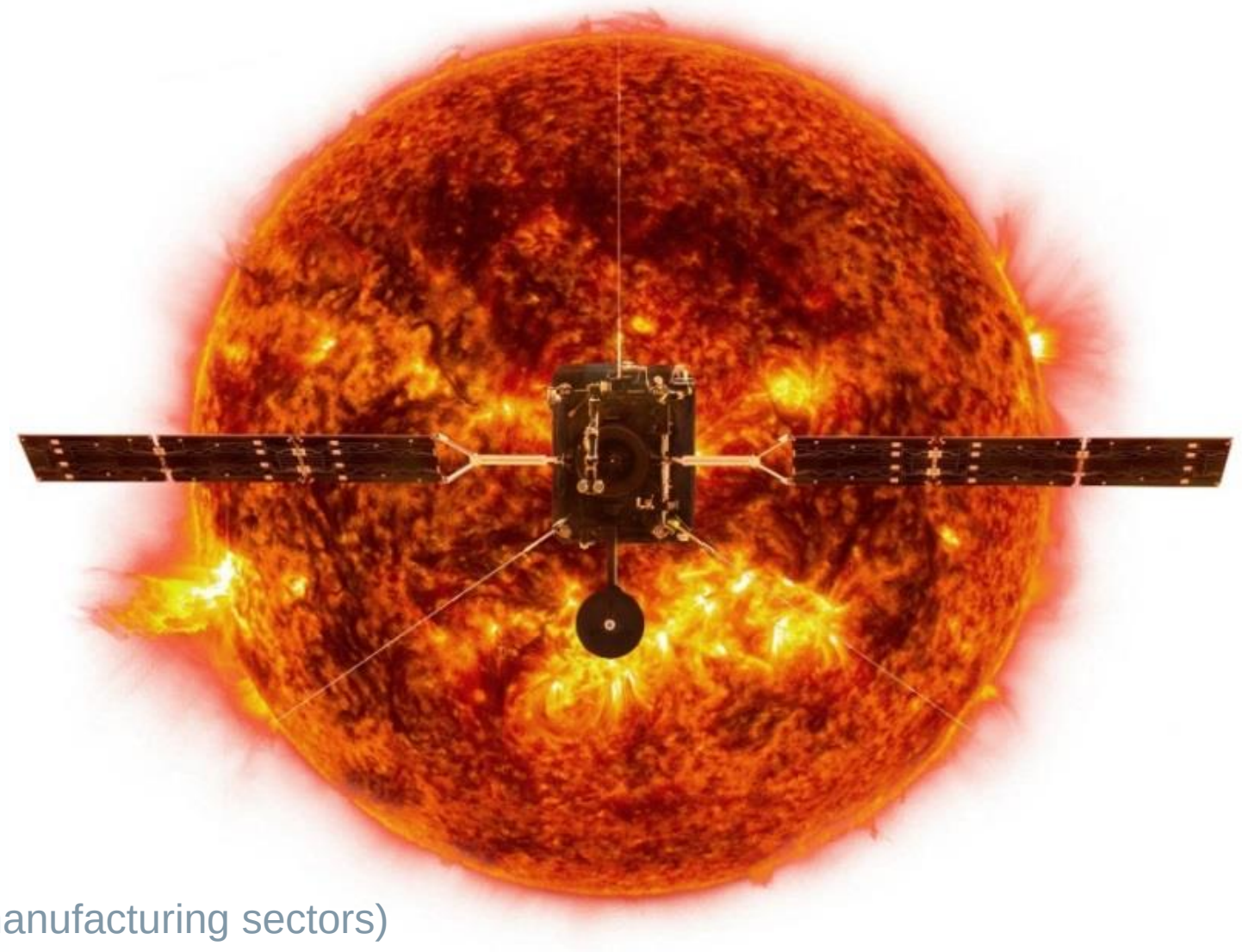
2nd compendium released end 2019

http://emits.sso.esa.int/emits-doc/ESTEC/News/GSTPAMCompedium2019.pdf

Case Study – Front Heat Shield for Solar Orbiter

- Peak Temperature ~ 520°C
- Exposed to 13 Solar Constants
- UV / VUV Radiation
- Electrons / Protons
- Thermal Cycling





- No off the shelf solution
- Identification of new technologies (other manufacturing sectors)

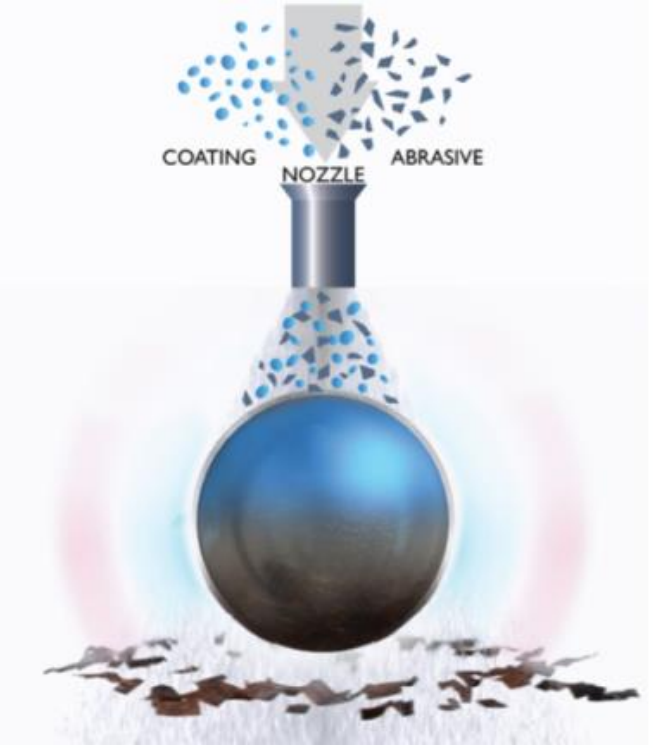
The Co-Blast Process

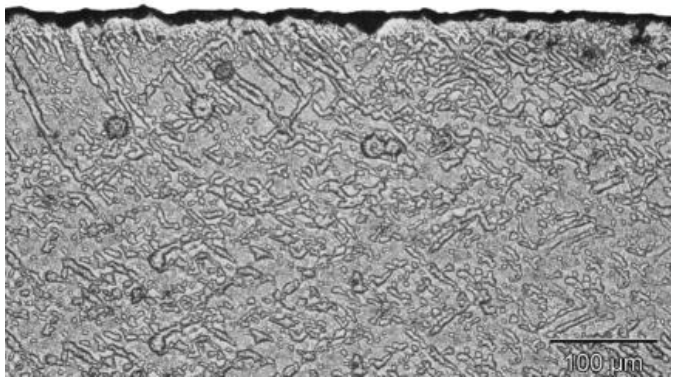
ENBIO™

- Originally Developed for Medical Implants
- **Abrasive** Material and **Dopant** Material

Original Titanium Screw

Screw coated with hydroxyapatite (HA)

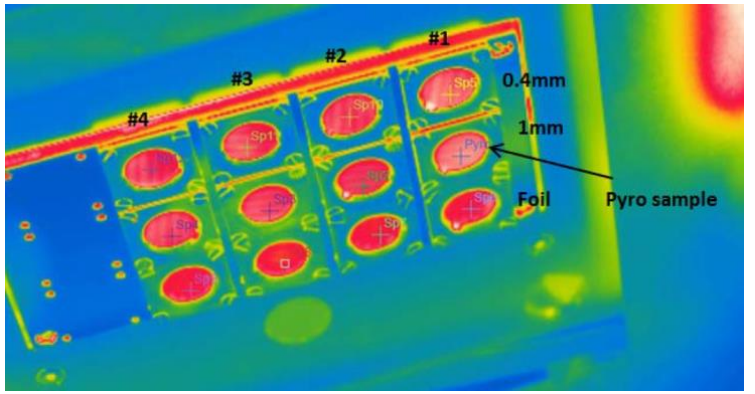




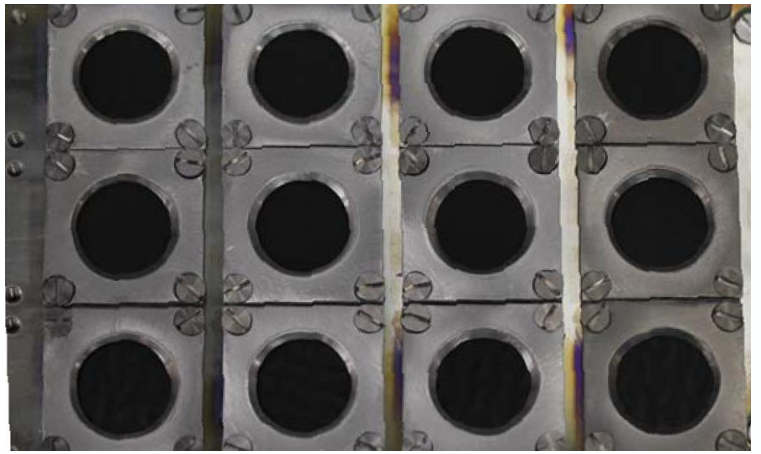
Co-Blast Technology

Small Coupon Testing

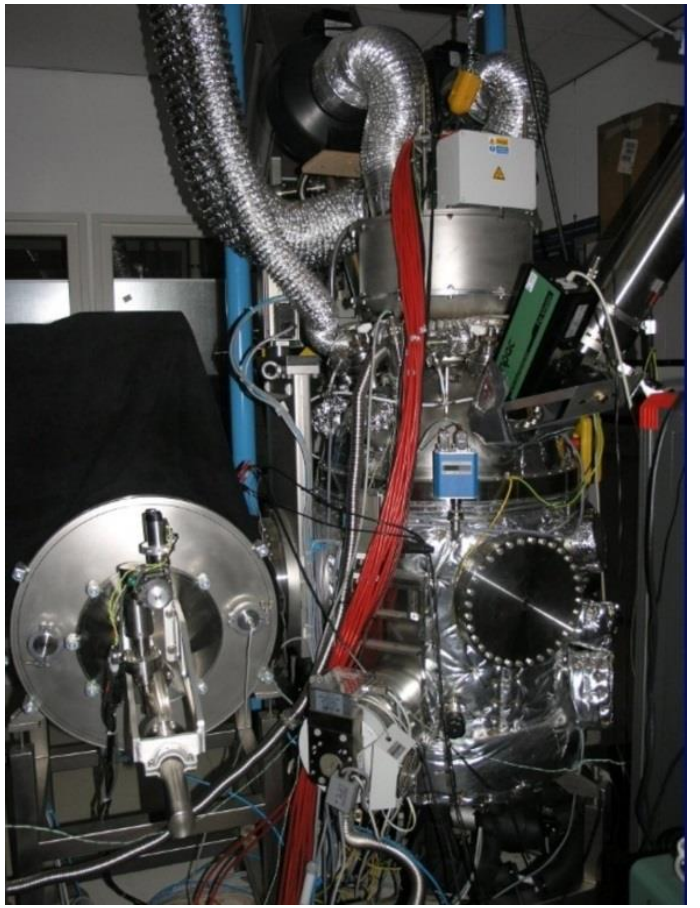
- Visual Examination
- Microscopic and spectroscopic examination (SEM/EDX, XPS)
- TGA / Outgassing
- Thermo-Optical Properties
- Electrical Resistivity
- Surface Roughness
- High Temperature Thermal Cycling
- Adhesion Testing
- Irradiation Testing (UV, VUV, electrons, protons – all at 500°C)



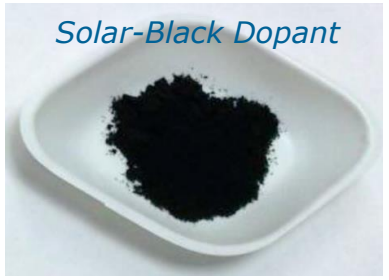
Infrared camera during VUV testing



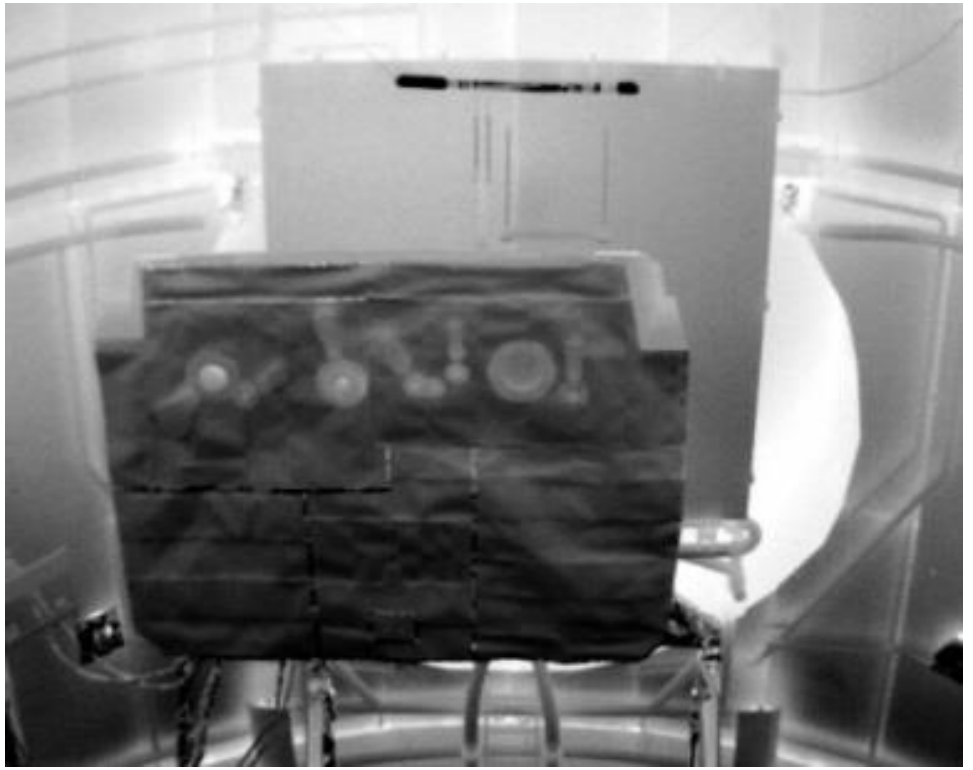
Coatings at end of UV testing



Synergistic Temperature Accelerated Radiation (STAR) Facility



Manufacture and Testing of Flight Hardware

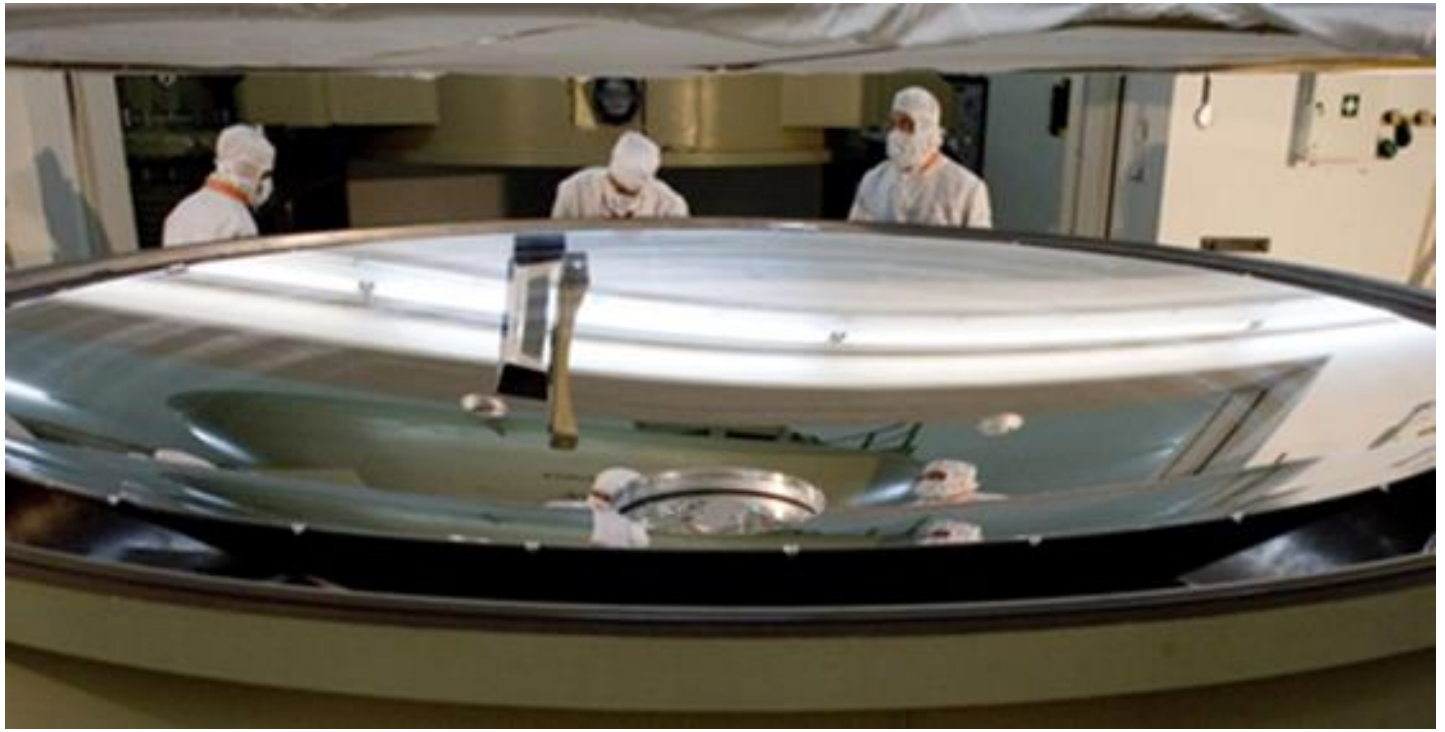


(left) Full size Heat shield entering the large space simulator at ESA (Right) under test

Case Study – Additive Manufacturing Competence Development

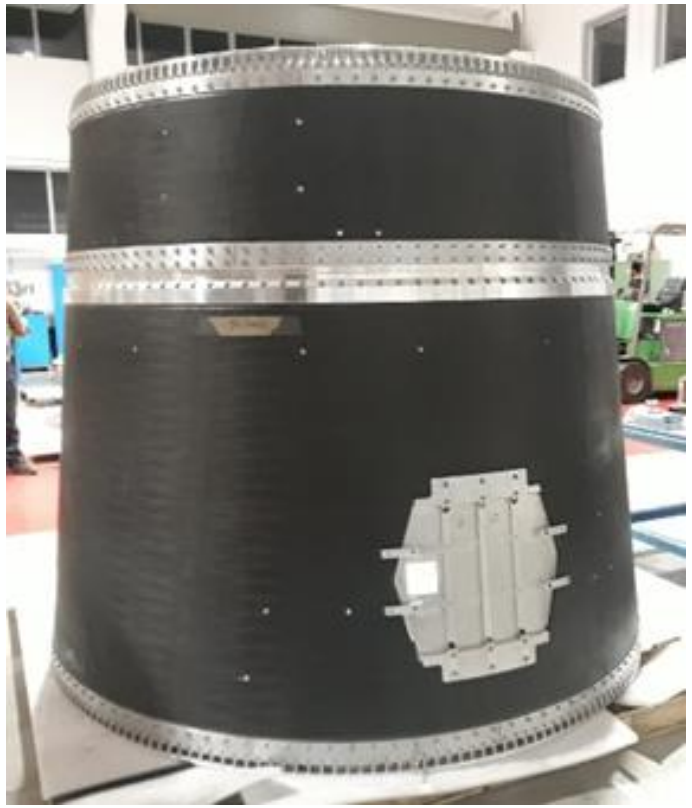
- SMEs who are interested in additive manufacturing but do not know if to adopt the technology
- Small 12 month activities
- All SMEs use the same technical partner (Fraunhofer IWS)
- SME selects the part
- Fraunhofer performs topological optimization and uses its knowledge to build and test each part.
- Agreed to share experience among all partners
- Spin-in/spin-off principle

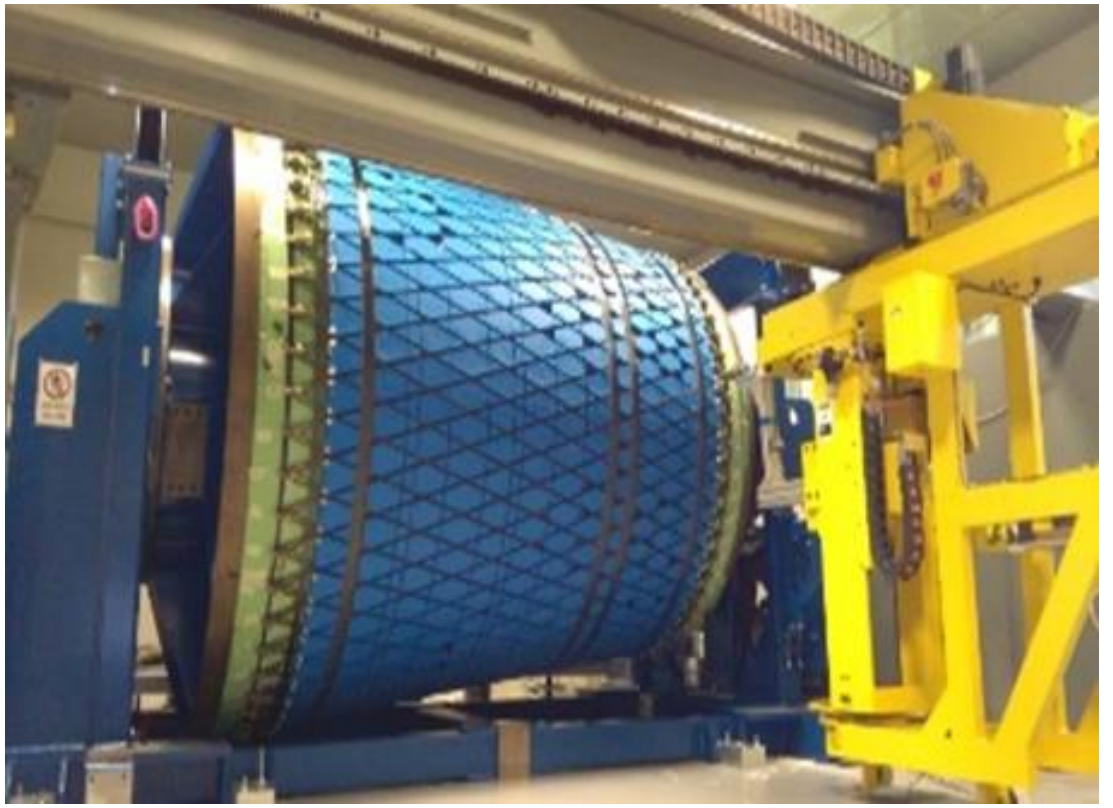
Examples of Advanced Manufacturing



Herschel Space Telescope primary mirror integrated (left) and the constituent SiC petals (right), the largest ever build with the selected manufacturing process.

Examples of Advanced Manufacturing

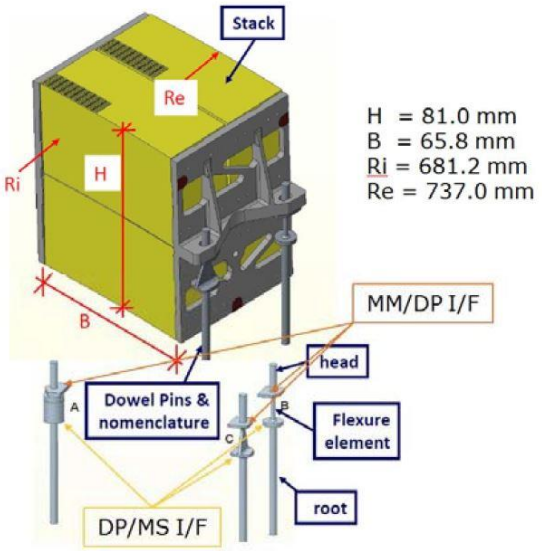


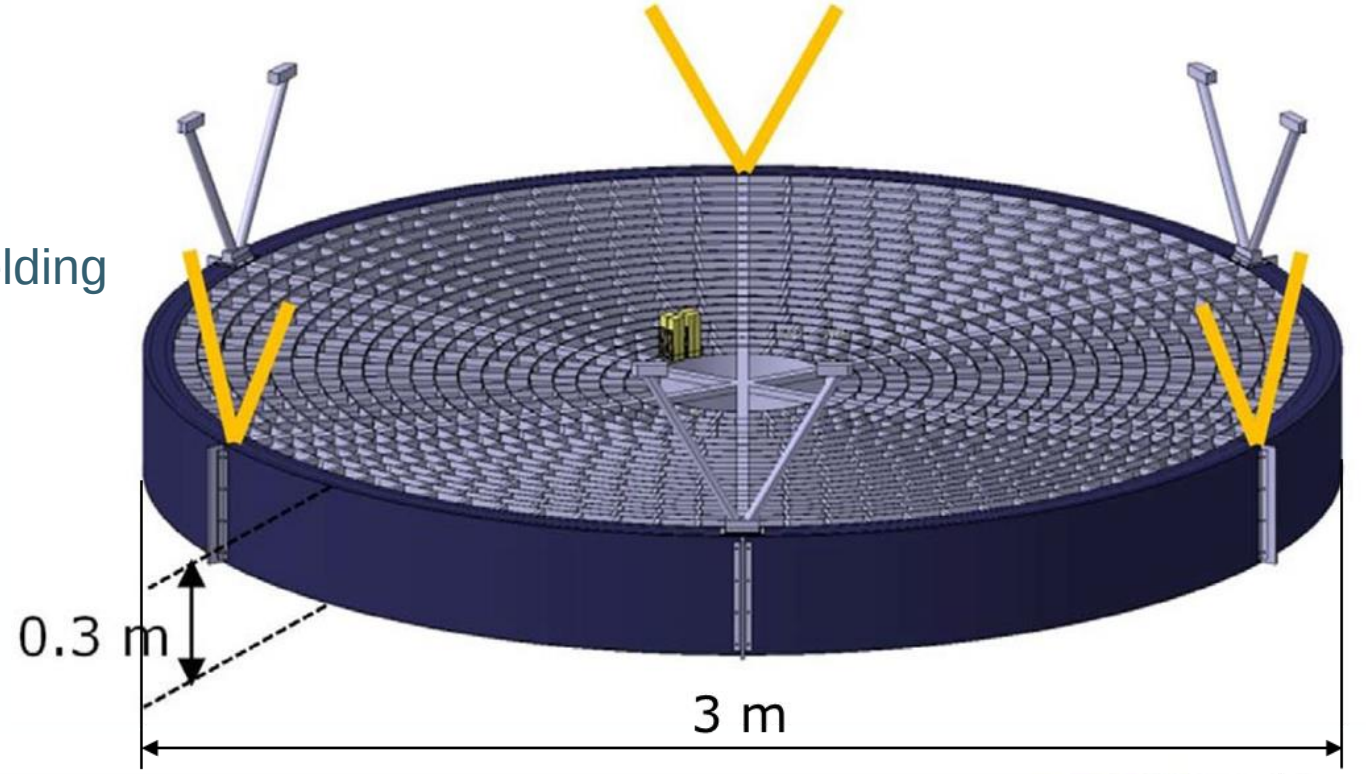


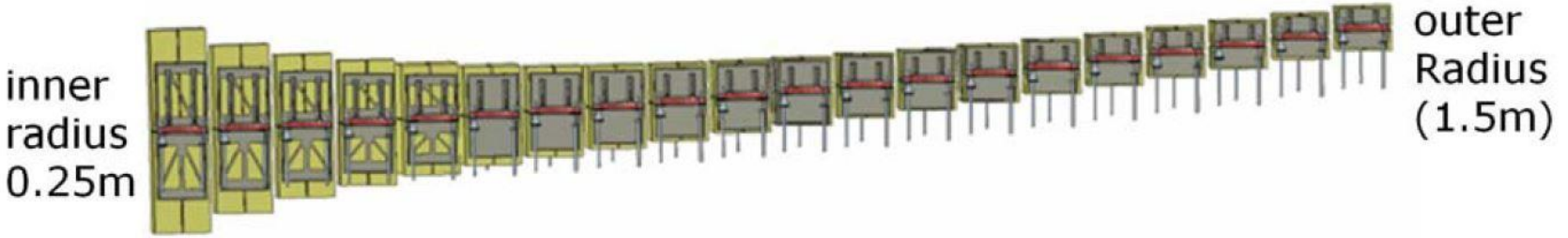
The interstage 2-3 of VEGA C Launcher manufactured using a composite grid structure technology

ATHENA Optical Bench with Additive Manufacturing

- Materials trade-off: E/ρ → max, CTE → low
- TRP project: **Ti alloy** chosen due to **manufacturability**
- Produced through Laser Powder Build-up Welding (LPBW) at Fraunhofer IWS

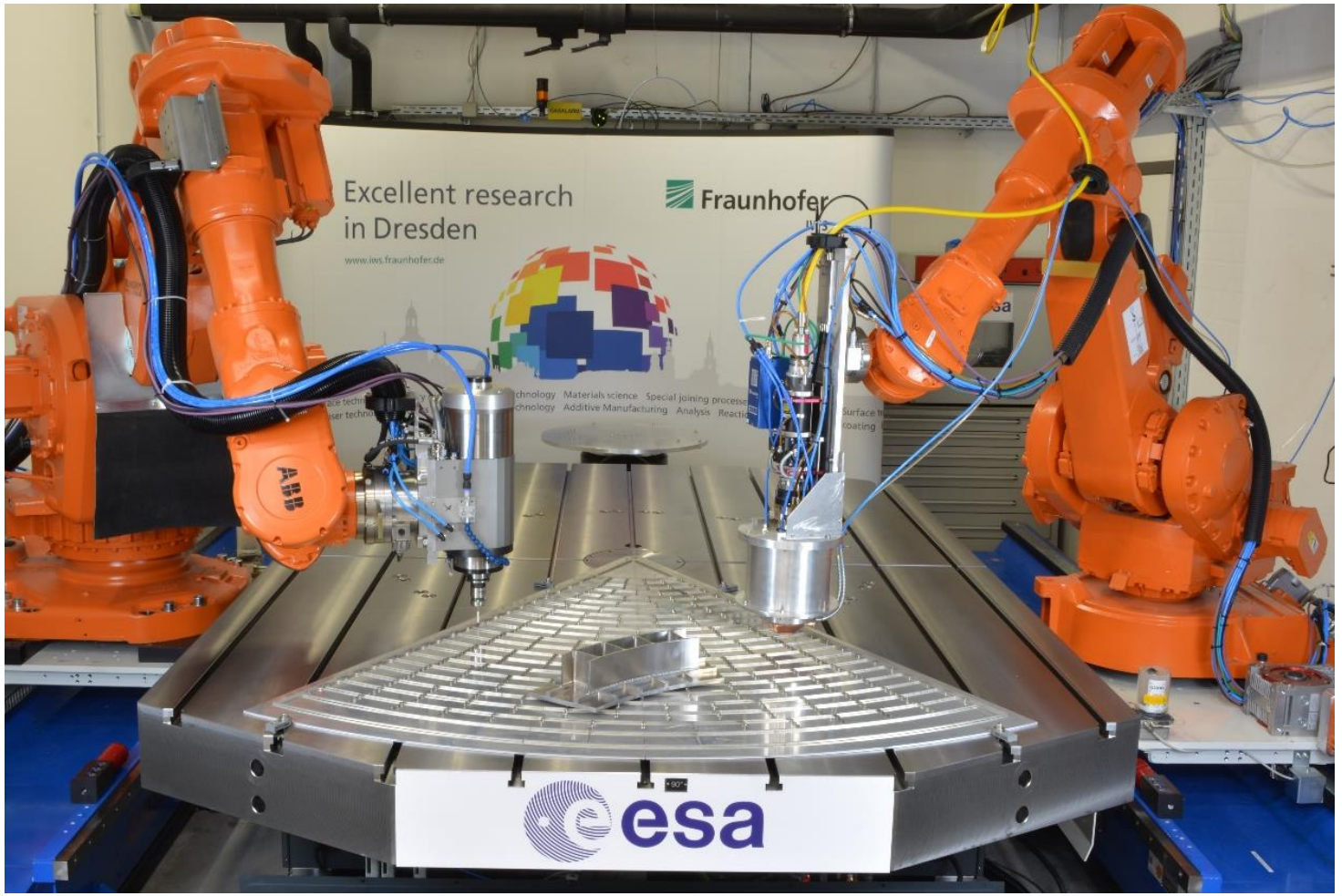






ATHENA Optical Bench with Additive Manufacturing

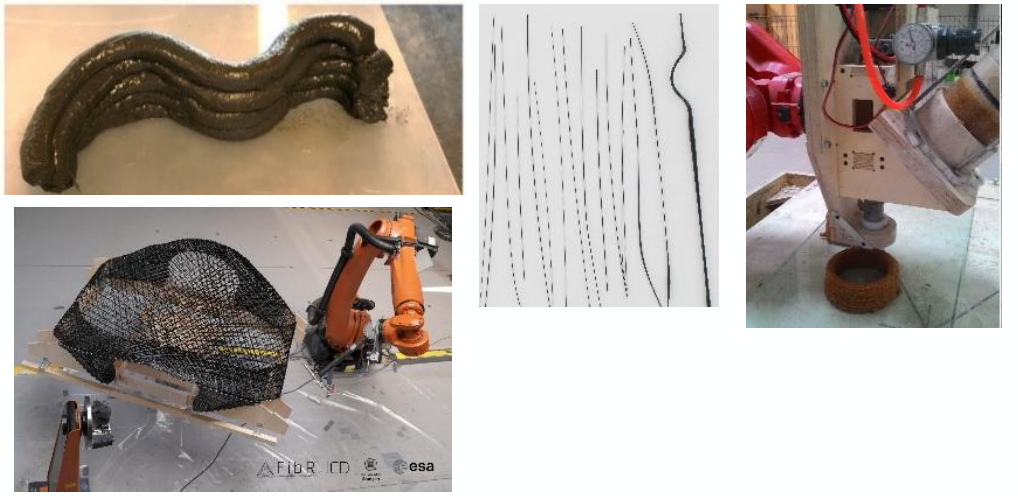
- **16 axis twin robot** system
- Turn-tilt table
- 1-2 robots performs **AM** task
- 1 robot performs **milling** task



Out of Earth Manufacturing

ISRU for Construction and Manufacturing

Development of AM processes for construction with regolith in previous GSP, TRP and GSTP activities 2012 – 2018



Advanced Concepts Team: Regolith-based geopolymers; Robotic manufacturing of fibrous structures; Moon fibres; Biocomposite printing

Spaceship EAC: Regolith microwave sintering

ESA Studies on AM for Future Human Exploration

URBAN

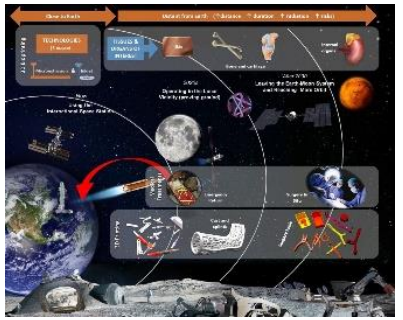
GSP 01/2018 – 12/2018

- Study on multiple uses of AM to build and maintain a lunar base
- Identified technologies for AM of polymers, metals, regolith, electronics, food, living tissues
- Semi-automated tool for selection of AM technique based on hardware needs

Conceiving a lunar base using 3D printing technologies

3D Printing of Living Tissues

GSP 2018 – 2019



- Demonstration of bioprinting of skin and bone samples independent of the gravity vector
- End-to-end roadmap established to enable 3D bioprinting for space exploration missions
- Input to future HRE payload

3D printing of living tissues for space exploration

- In-situ and in-orbit manufacturing are mentioned in the first ESA Space Resources Strategy led issued in May 2019
- Can address e.g. the processing of the material by-products in the ongoing efforts on oxygen extraction from regolith

Thank you for your attention!

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