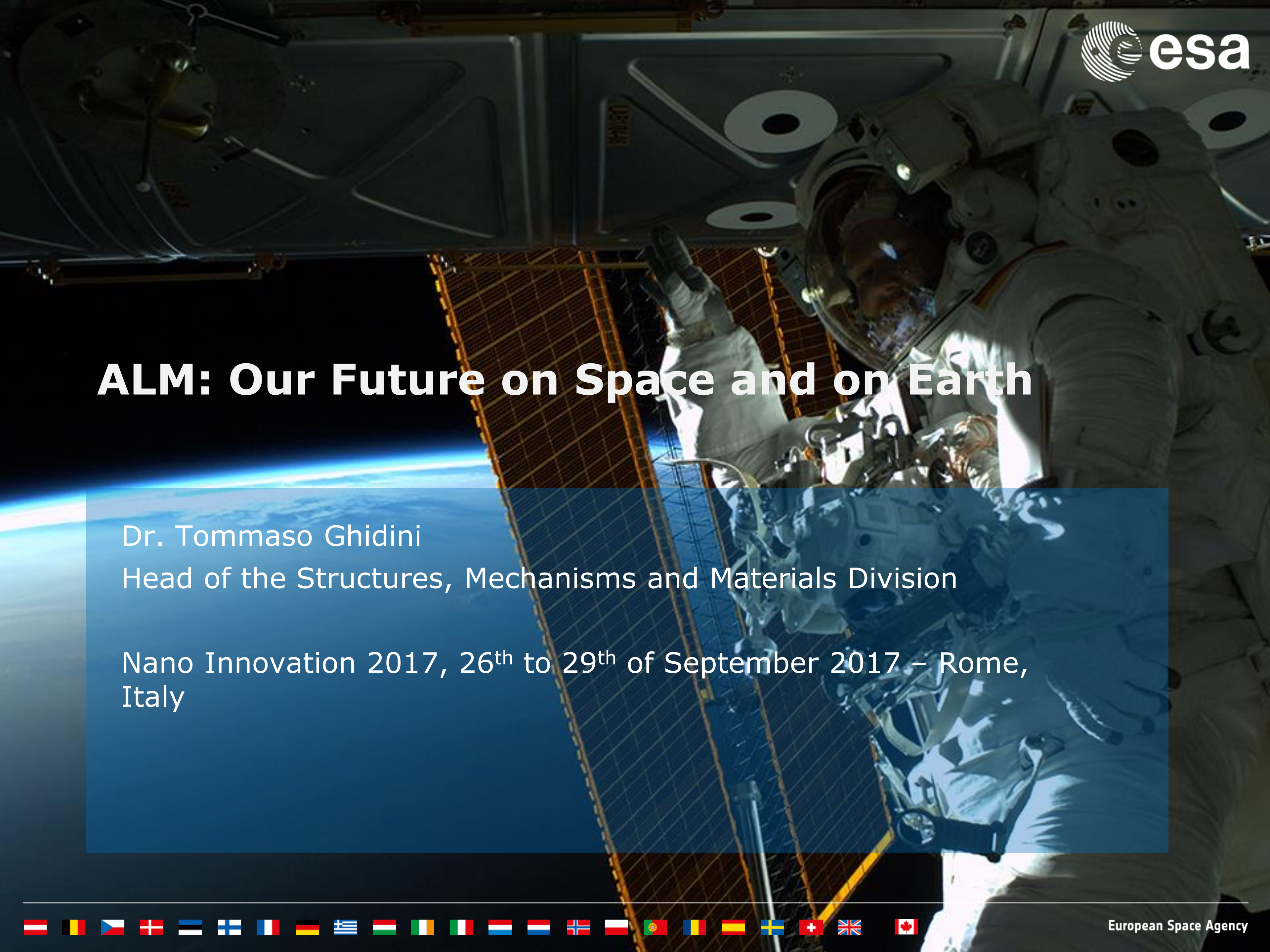


ALM: Our Future on Space and on Earth

Dr. Tommaso Ghidini

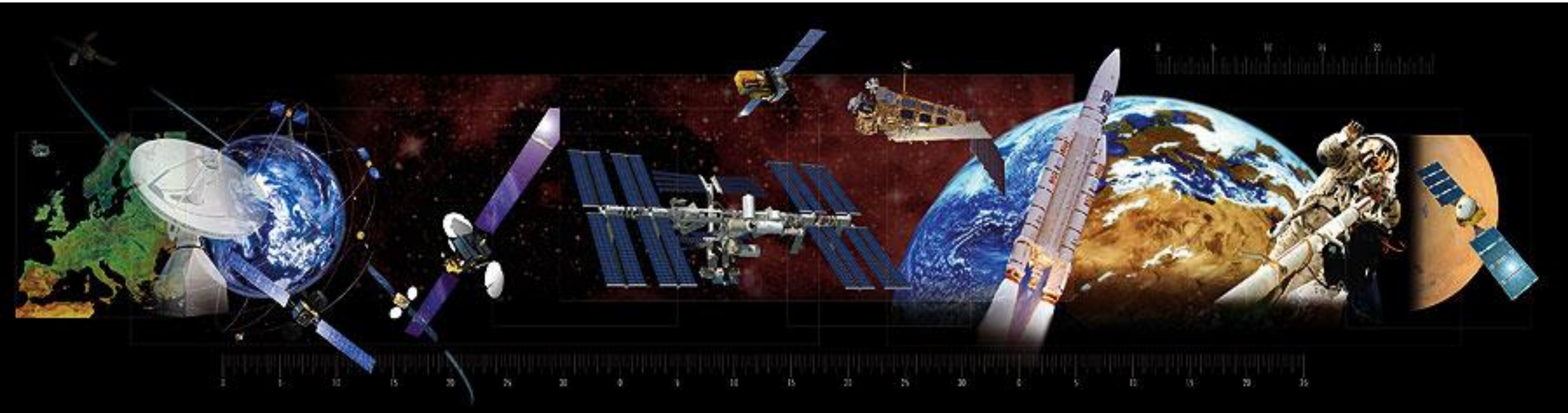
Head of the Structures, Mechanisms and Materials Division

Nano Innovation 2017, 26th to 29th of September 2017 – Rome, Italy

ESA's Activities

ESA is one of the few space agencies in the world to combine responsibility in nearly all areas of space activity

1. **Space science**
2. **Human spaceflight**
3. **Exploration**
4. **Earth observation**
5. **Launchers**
6. **Navigation**
7. **Telecommunications**
8. **Technology**
9. **Operations**



AM: Enabling Technology for Future Space Missions

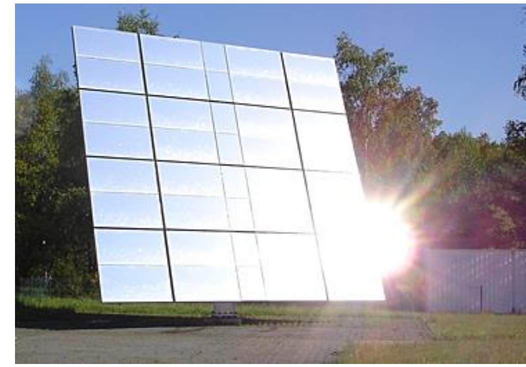
Enabling Industry to maximise benefits of the technology requires:

1. Reach confidence and quality required for space use
2. Change the way we think/work today

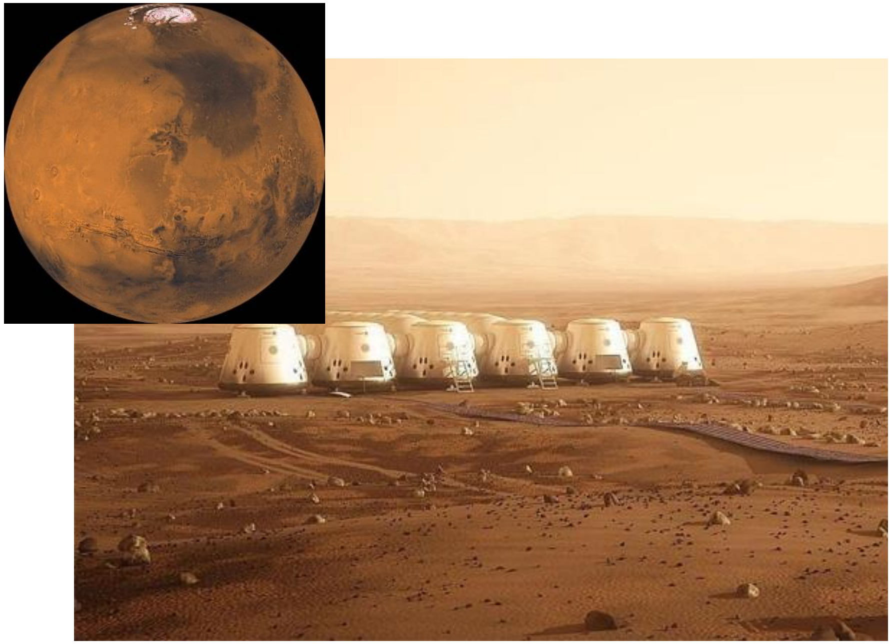
AM: Enabling Technology for Future Space Missions – ESA/DLR

Main Objectives/Benefits:

- To develop a 3D-printing process for fusing/melting/sintering model lunar soil material with concentrated solar energy
- To optimize the overall process (setup, parameters) in view of application on the Moon
- To produce one (possibly several) brick-sized model building blocks of lunar base outer shell
- Polymers + Metals Recycling Routes on the Moon

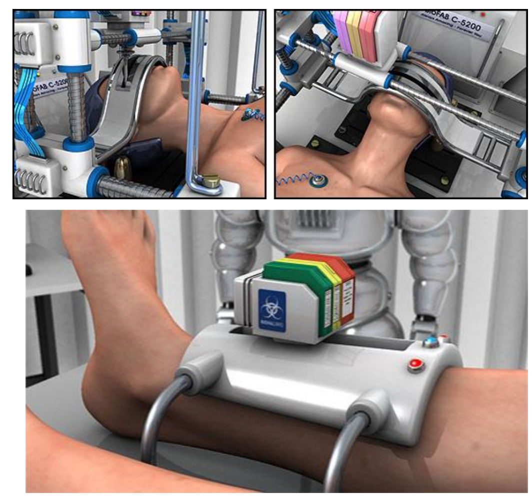


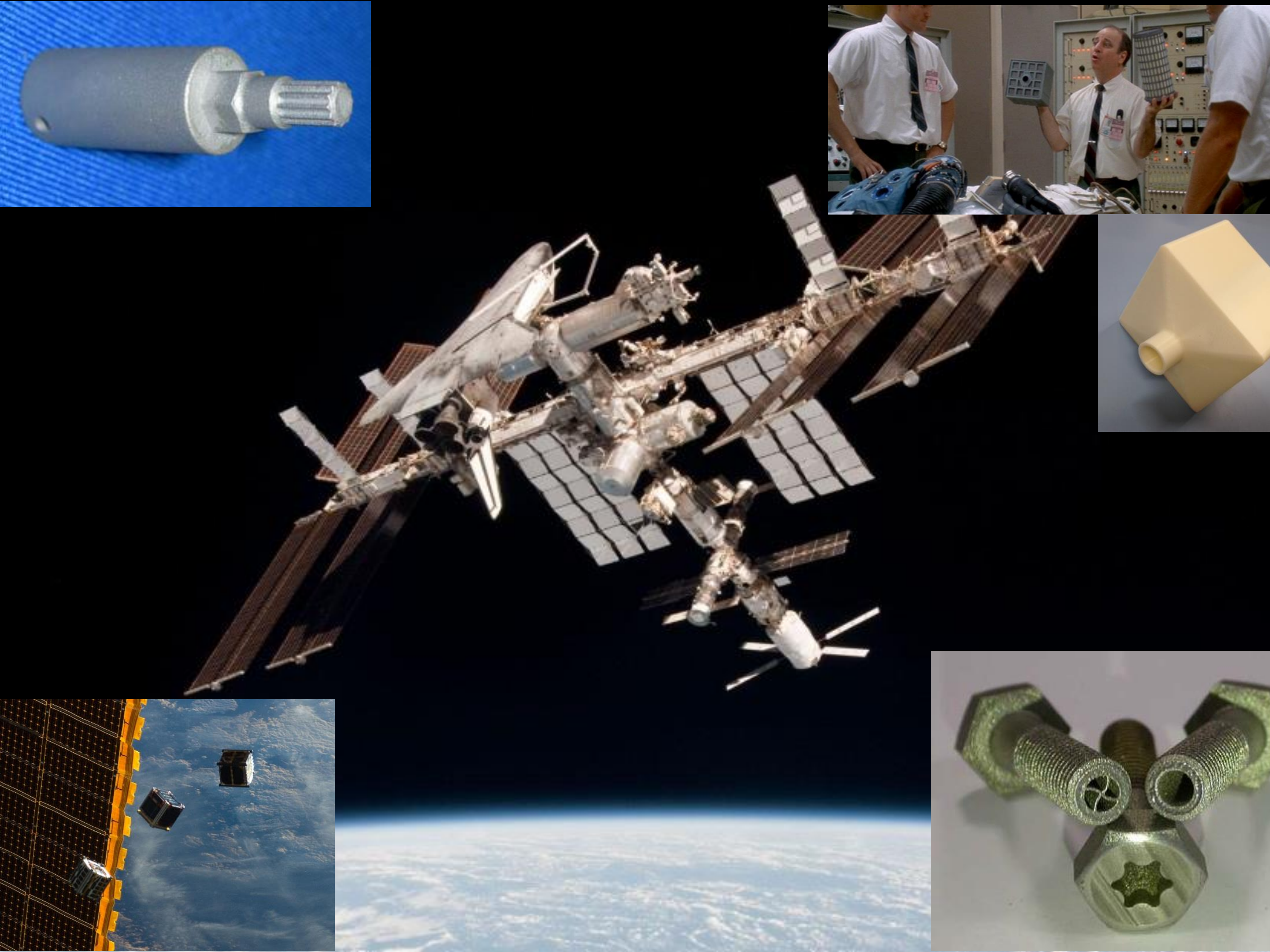
New Exploration Mission Approach



Printing using in-situ resources and power optimization for Moon, Mars and beyond

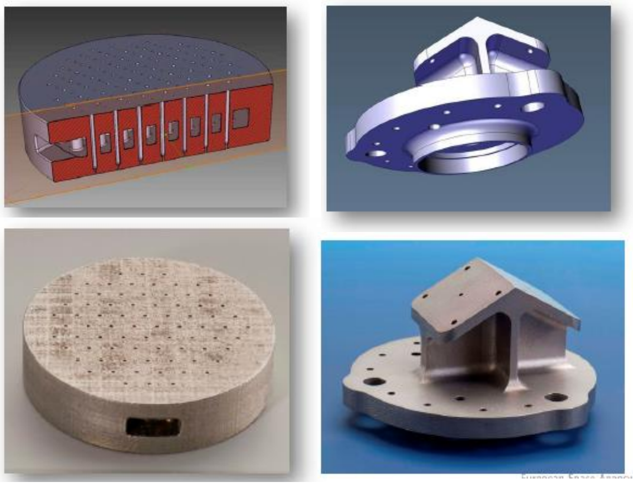
Printing of Living Cells, Organs and blood



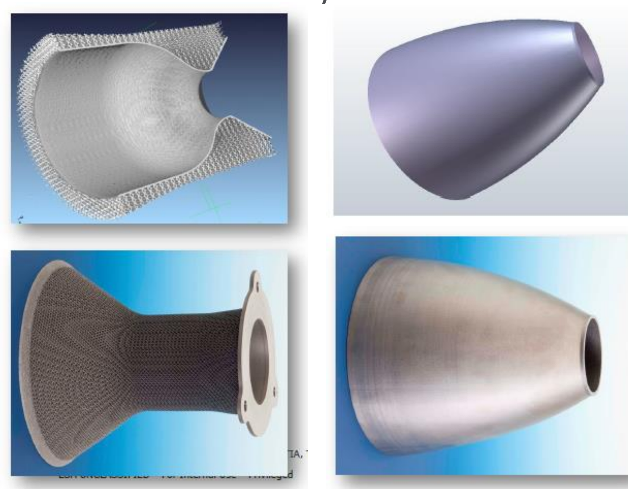


AM for Space Propulsion

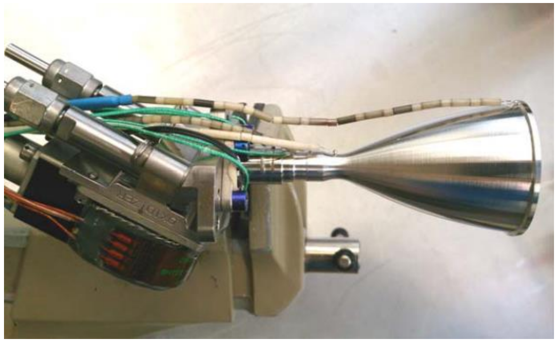
Injectors

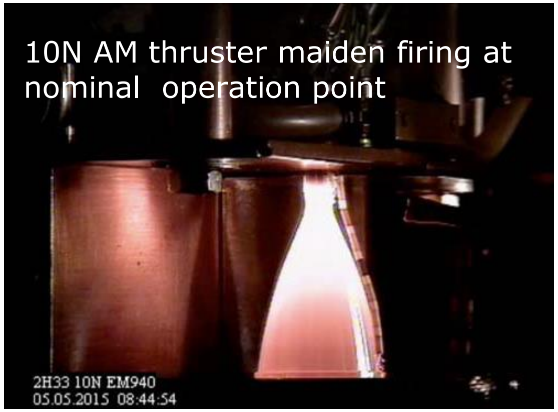


Chamber/Nozzles

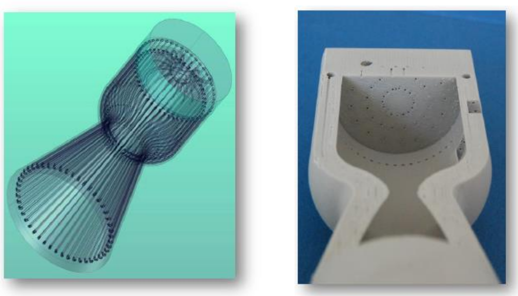


First in the World

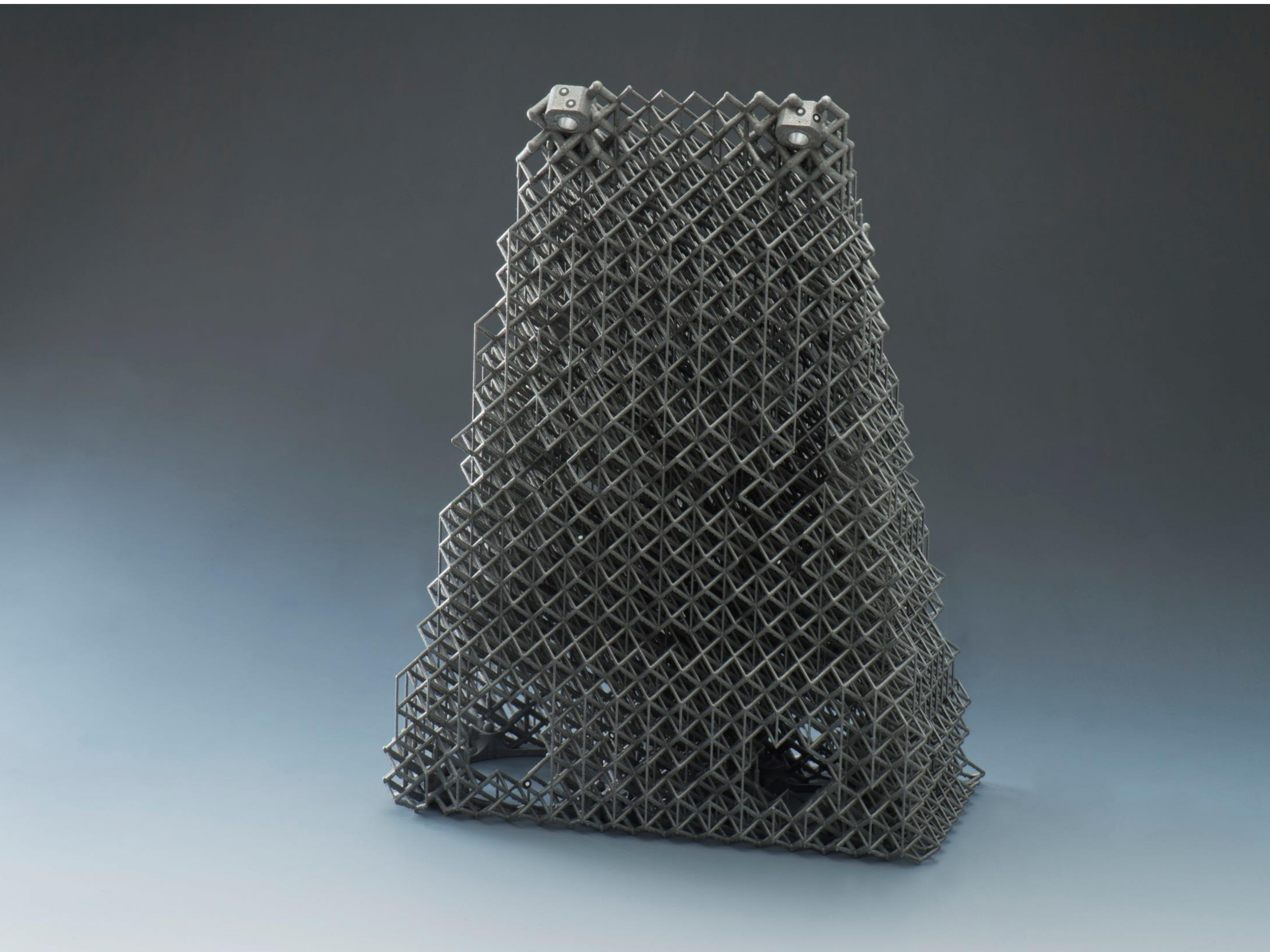




Monolithic Thrusters

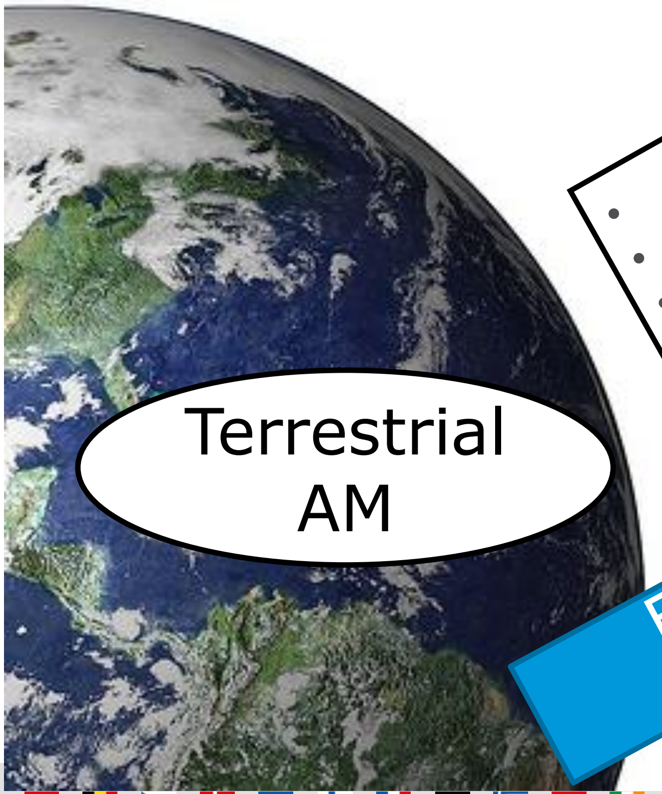


- Functionally graded materials with gradual transition in composition and structure for thruster performances improvement
- Reducing incompatibilities in material properties (e. g. CTE)
- Enhanced monopropellant catalyst design
- Lattice structure for thermal/weight management
- Platinum now economically viable



European Harmonisation Roadmap on Additive Manufacturing for Space

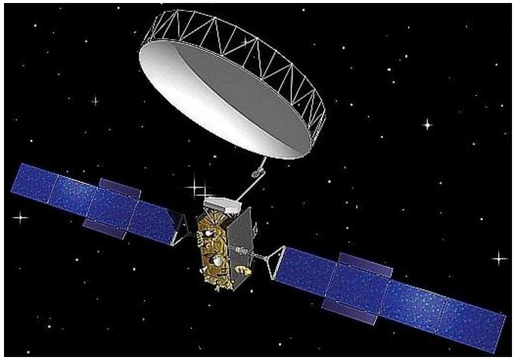
- Roadmap proposes about 30 types of parts (AIM A)
- Roadmap proposes technology developments (Aims B to F)
- **Roadmap endorsed by the IPC**



Terrestrial AM

- Aim B: Design
- Aim C: Material supply
- Aim D: Processing
- Aim E: Post processing
- Aim F: Qualification
- Aim G: Standardisation

End-to-end AM process

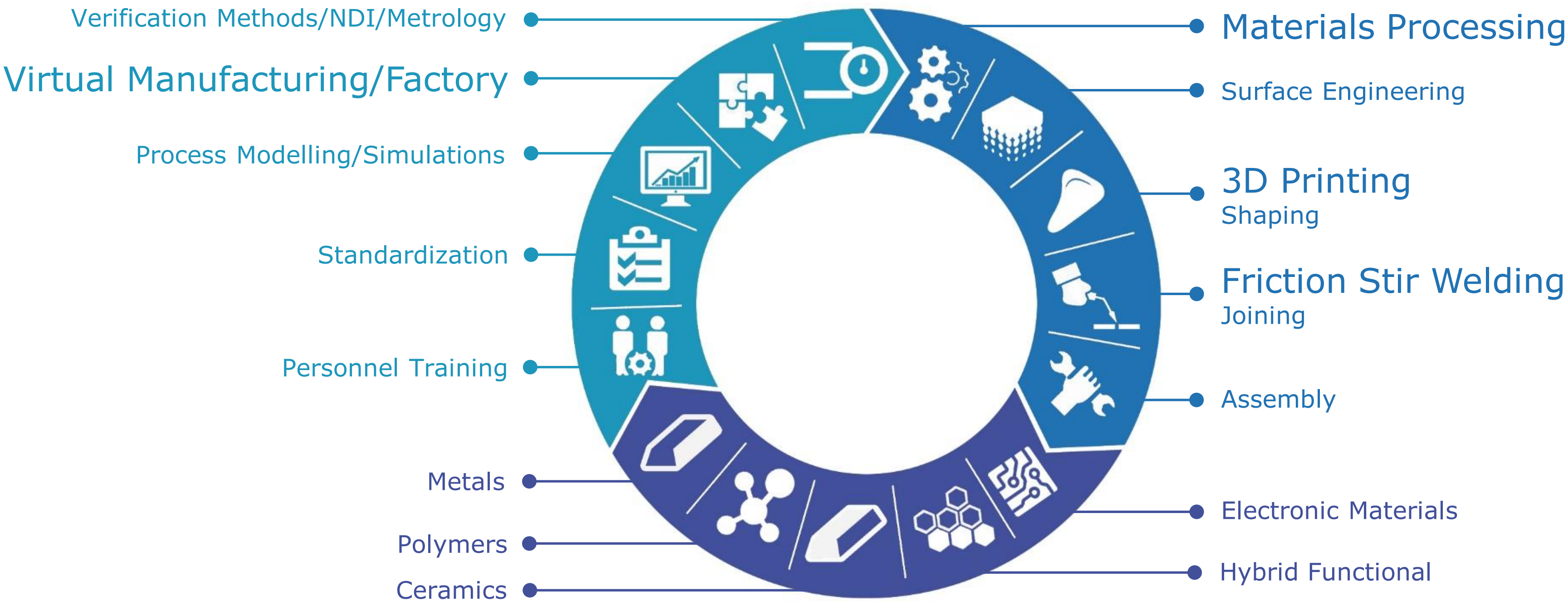


Aim A

- More than **700 experts** /stake holders involved
- **26 countries** represented
- **390 companies** represented
- **62 new members** joined the roadmap space community
- Available for everyone in Europe
- => Eurospace

Image source: dragoart.com

ESA Advanced Manufacturing Cross Cutting Initiative

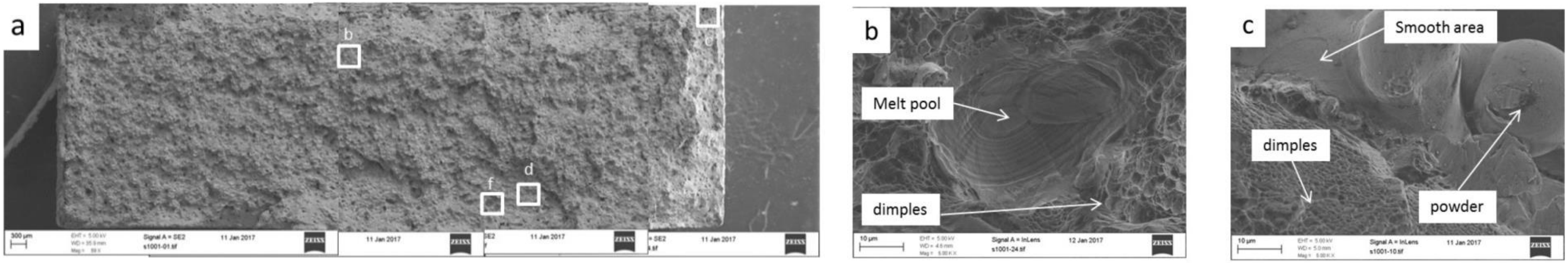


TEC-MSP 2016/7 R&D Programme
GSTP Advanced Manufacturing Compendium

ID#	Activity	Budget (k€)	Committed Support
G61A-005MS	Integrated Optical Fibres in Launcher and Spacecraft Composite Structures	500	500 (PL)
G61A-006MS	Powder Metallurgy Based Materials for High Wear Resistance, High Hardness and High Temperature	600	600 (BE), 600 (DE), 600(UK)
G61A-009MS	3D Honeycomb for curved structure manufacturing	600	600 (LU)
G61A-011MS	Advanced Forming Technologies for Complex Shapes	3000	1500 (BE), 1150 (DE), 750 (UK), 180 (PT)
G61A-018MS	Additive Manufacturing Powder Material Supply Chain: Verification and Validation	1000	400 (IE), 750 (UK), 700 (SE), 1000 (BE), 1000 (DE)
G61A-021MS	Primary Structures made by Additive Manufacturing	1200	1000 (LU), 1200 (BE), 600 (UK)
G61A-025MS	Development of Design Methods for AM including CAD Design / FEM analysis / Manufacturing features	900	900 (BE), 900 (DE)
G61A-033MS	Development of a Compliant Mechanism Based on Additive Manufacturing	500	500 (UK), 500 (BE) 500 (DE), 450 (LU), 500 (CH)
G61A-019MS	Advanced aluminum alloys tailored for Additive Manufacturing space applications, targeting high end structural spacecraft parts	900	800 (LU)
G61A-026MP	Additive Manufacture of In-space Engine chambers	2000	1450 (LU)
G61A-036MS	Assessing the use of Advanced Manufacturing to improve and expand space hardware capabilities	5000	2000 (DE), 1000 (BE), 500 (AT)
G61A-032MM	Development of low aerial density Aluminum alloys mirrors using Additive Manufacturing	400	400 (BE)
G61A-017QT	High Density PCB Assemblies	1800	1800 (BE)
G61A-019QT	Advanced Aluminum alloys tailored for Additive Manufacturing space applications, targeting high end structural parts	900	900 (BE), 800 (LU)
G61A-027MS	Development of embedded thermal functions in structural parts using 3D printing	900	900 (BE), 900 (D)
			28230 k€

ESA-RAL Advanced Manufacturing Laboratory - TRP

- ESA Harwell Advanced Manufacturing **Test Services**
- Complementing the existing TEC-MS network of external facility
- **Pre-screening** of advanced materials and manufacturing processes towards space flight qualification
- **ALM capabilities** available



ESA Additive Manufacturing (AM) Benchmarking Center - UK

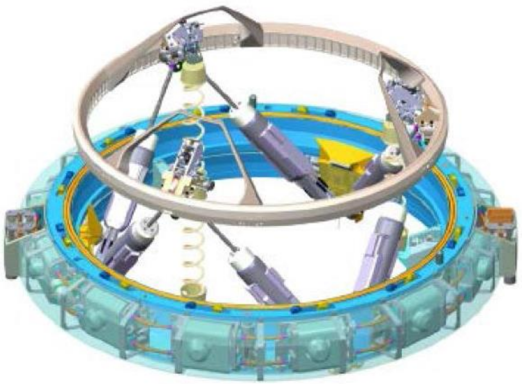
- **Additive Manufacturing** of hardware for space applications
- **Small, medium and large parts**
- Services to be **offered to ESA Projects/ESA Directorates** allowing access to state-of-the-art 3D Printing capabilities (metallic/non-metallic)
- Services to **offered to industry to mature their AM products** and process understanding
- Characterization of AM powders and produced materials
- Post processing of AM parts
- Failure investigation/re-manufacture of parts
- Comparison of AM machines
- Publication of a **European Newsletter** with all results generated by the Centre
- **Consolidate European leadership on AM**

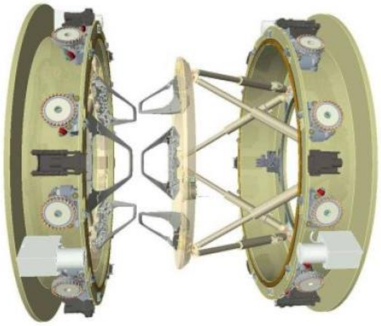
ESA Additive Manufacturing (AM) Benchmarking Center – Coventry UK - TRP

IBDM Ring

Objectives: Improve the IBDM ring in terms of:

- **mass**,
- **cost** and
- **environmental** impact (LCA).



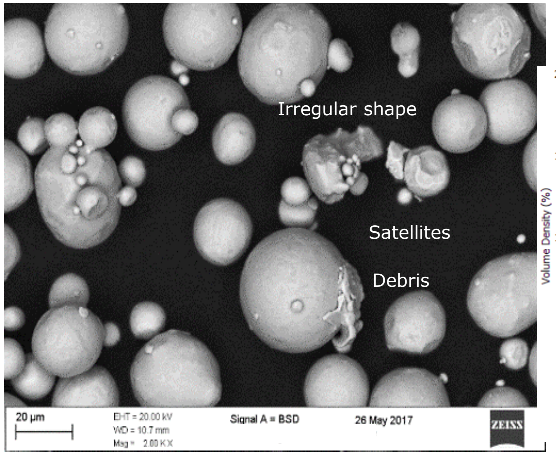


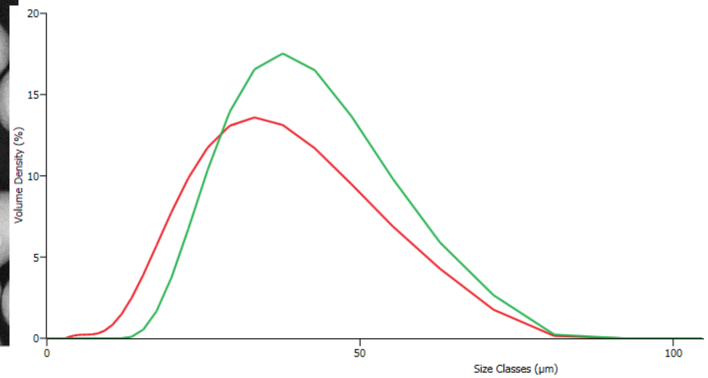
Docking photo: Soyuz spacecraft docked to ISS (Photo: NASA)

Compilation of powder supplier capability database

- Ongoing work program to characterize ALM powder properties
- Benchmarking of methodology ongoing between different European laboratories
- Draft a first attempt standard for powder procurement defining properties for a "space grade powder"

	Appearance	Flow properties	PSD Laser	Morphology	Chemistry Contamination	Porosity
Supplier A	Grey, no agglomerates	Good flowability	D10 = 23.9 D50 = 37.0 D90 = 56.2	59 % spheroidal 38 % spherical 2.8 % angular Smooth surface	Within spec.	Some pores
Supplier B	Grey, strong agglomeration	Bad flowability*	D10 = 16.9 D50 = 31.4 D90 = 52.7	66 % spheroidal 31 % spherical 2.4 % angular Some surface dents	Within spec.	Some pores and internal defects





Malvern MS 3000 particle analyser

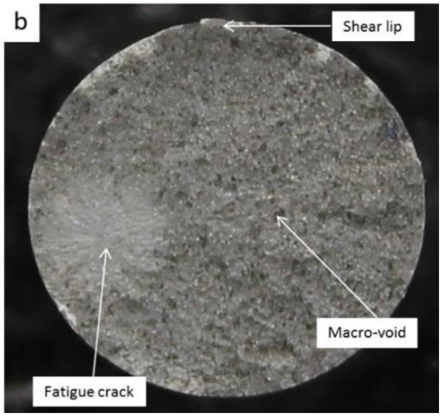
Additively Manufactured copper materials for launcher engines

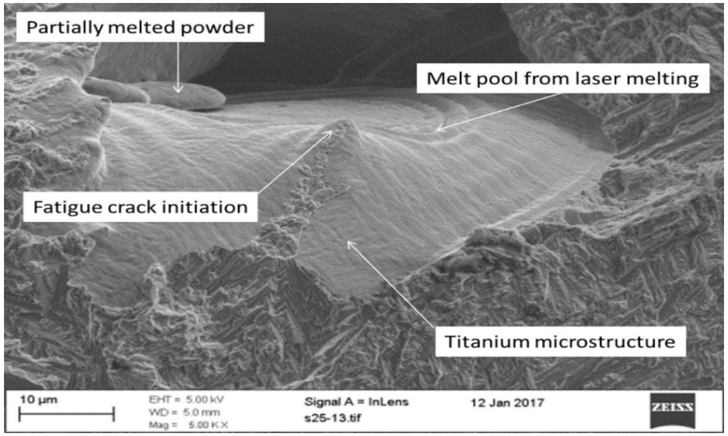
Objectives:

- Costs + Lead Time Reduction + Performances
- Investigate material properties of copper alloys suitab for launcher liquid propulsion and Additive Manufacturing
- Produce and assess crucial features of a VEGA TCA liner: cooling channels, overhangs etc.
- Investigate manufacturability of the TCA: distortion, dimensional accuracy etc.

Compilation of fractography Atlas for ALM manufactured materials

- Testing of different materials for fracture strength and "fractography signatures" is ongoing for a range of additively manufactured materials and build conditions
- Materials investigated to-date include Ti-6Al-4V, 316L stainless steel and AlSiMg
- The information and image data is being collated into a fractography reference document ("Atlas") to be used as an ESA materials database

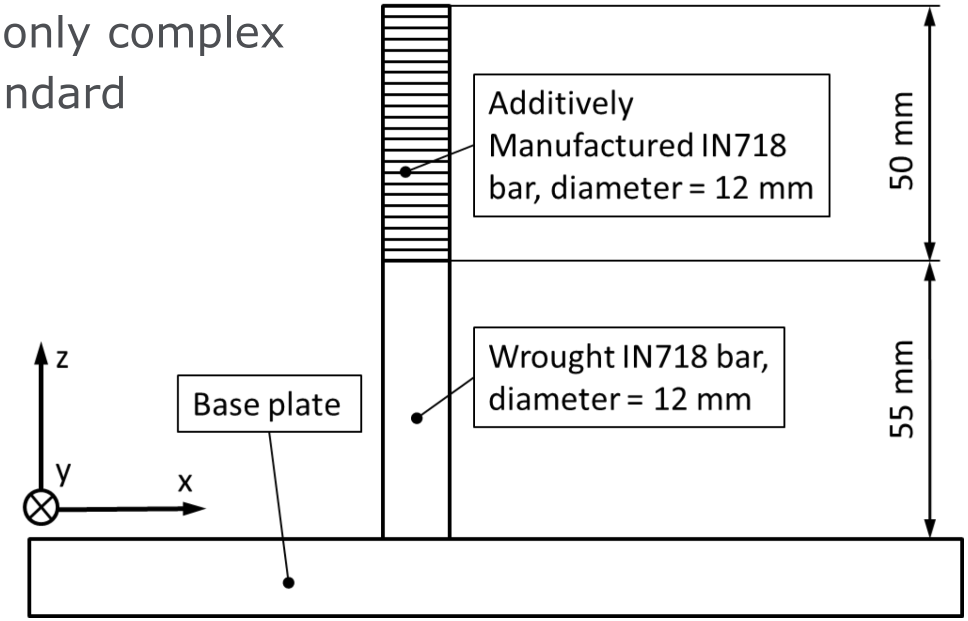




Additive Manufacturing of hybrid IN718 parts

Objectives:

- Investigate intersection from wrought IN718 to Additively Manufactured IN718
- Will be assessed through mechanical and microsectional investigation
- Targeted applications of AM hybrid components:
  Liquid propulsion elements
- Expected benefits: cost reduction, as only complex parts would be produced with AM, standard geometries through machining



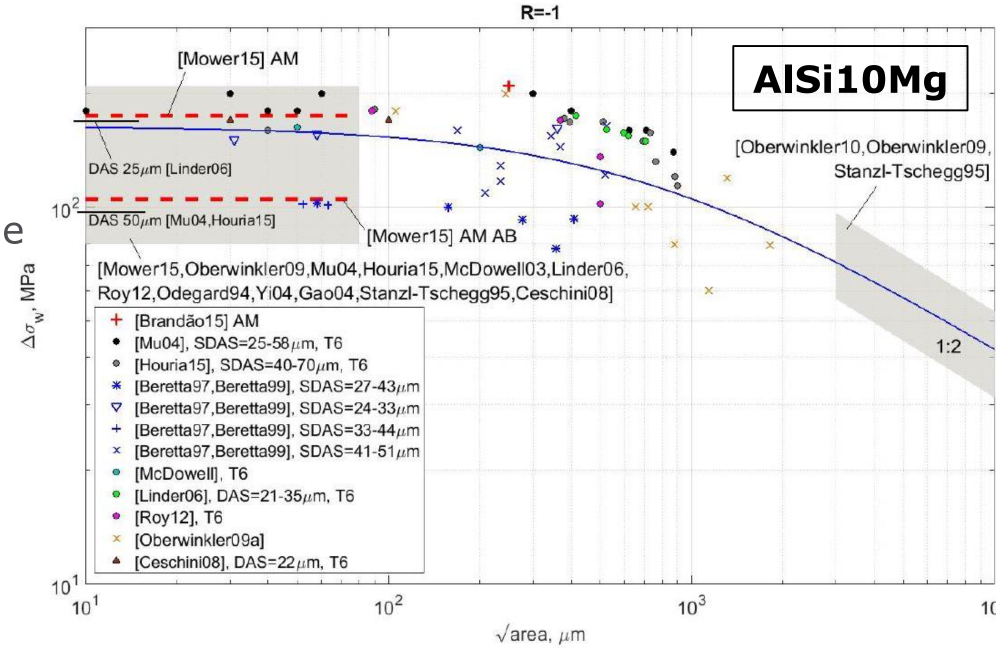
Damage Tolerance Route for Additive Manufacturing

Probabilistic fatigue life assessment

Collaboration with **Politecnico Milano** (Prof. Beretta) and **RUAG** Switzerland (Mr. Gschweitl), PhD Student: **Simone Romano**

POLITECNICO
MILANO 1863

- **Defects inherently** present in AM components
- Which defects will lead to **failure**? => max. defects
- **Estimation** of maximum **defect** in a volume => CT scanning of sub volumes and peaks over threshold maxima sampling
- => allows to **estimate** the **fatigue resistance**
- **Reduction** of CT scan **resolution** on full scale bracket, just enough to detect (largest) “killer defects”

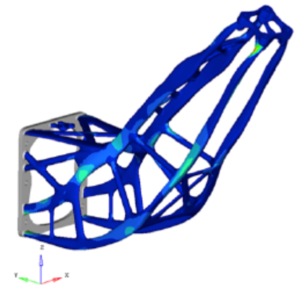


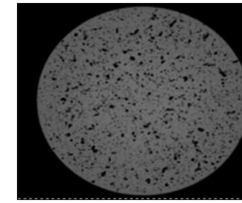
End-to-end Additive Manufacturing

Computational framework:

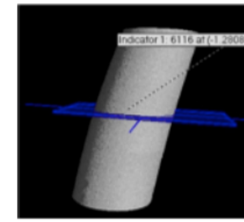
- Failure probability of every element and of the whole component
- Implementation in a commercial FE software (Abaqus subroutine)
- Implementation in the ESACRACK software Tool for all ESA Space Missions

Structural Analysis

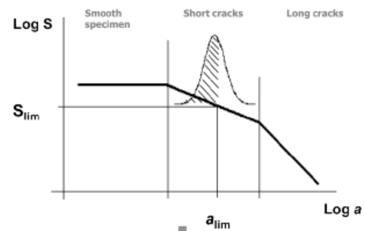




CT scans

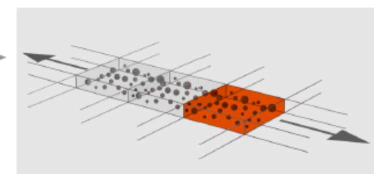


Fatigue strength as a function of defect size



Probabilistic model for fatigue strength of the material

Finite Elements inherently containing defect distribution



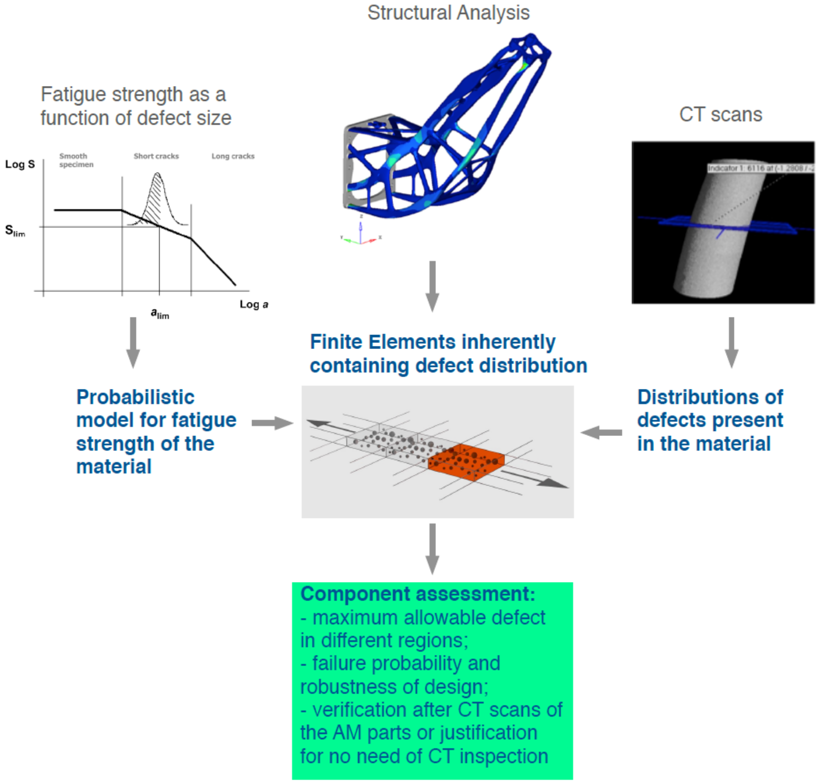
Distributions of defects present in the material

Component assessment:
- maximum allowable defect in different regions;
- failure probability and robustness of design;
- verification after CT scans of the AM parts or justification for no need of CT inspection

Probabilistic fatigue life assessment of AM parts as part of ESACRACK

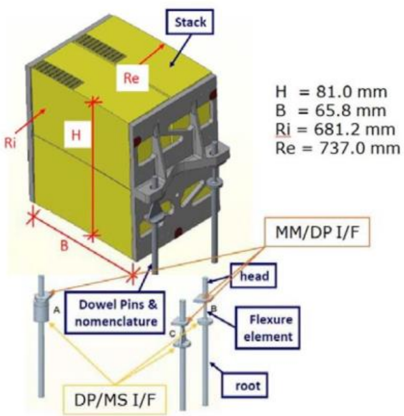
Objectives:

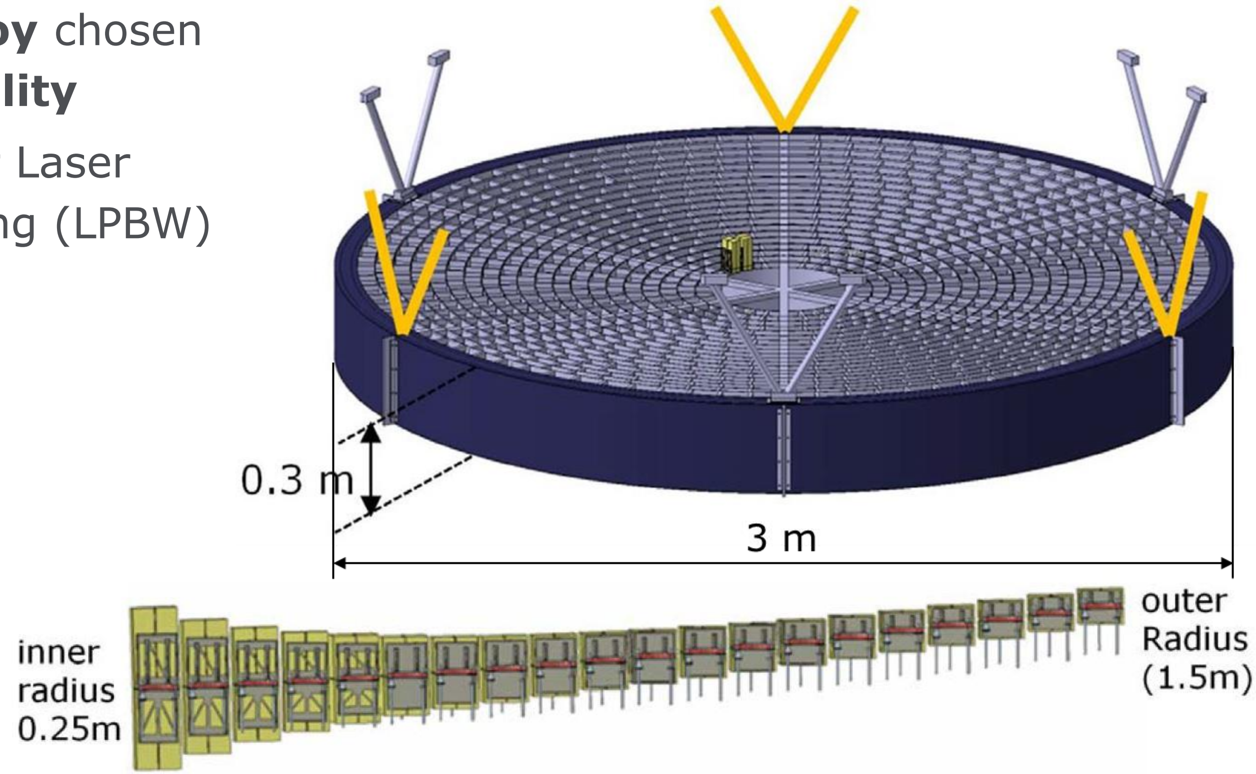
- Definition of sub-tasks required for probabilistic fatigue life assessment of AM components
- Implementation of probabilistic fatigue life assessment sub-routine into ESA-crack
- Study case: Assessment of the failure probability of the RUAG sentinel bracket



ATHENA optical bench with Additive Manufacturing

- For TRP project: **Ti alloy** chosen due to **manufacturability**
- Produced through laser Laser Powder Build-up Welding (LPBW) at Fraunhofer IWS



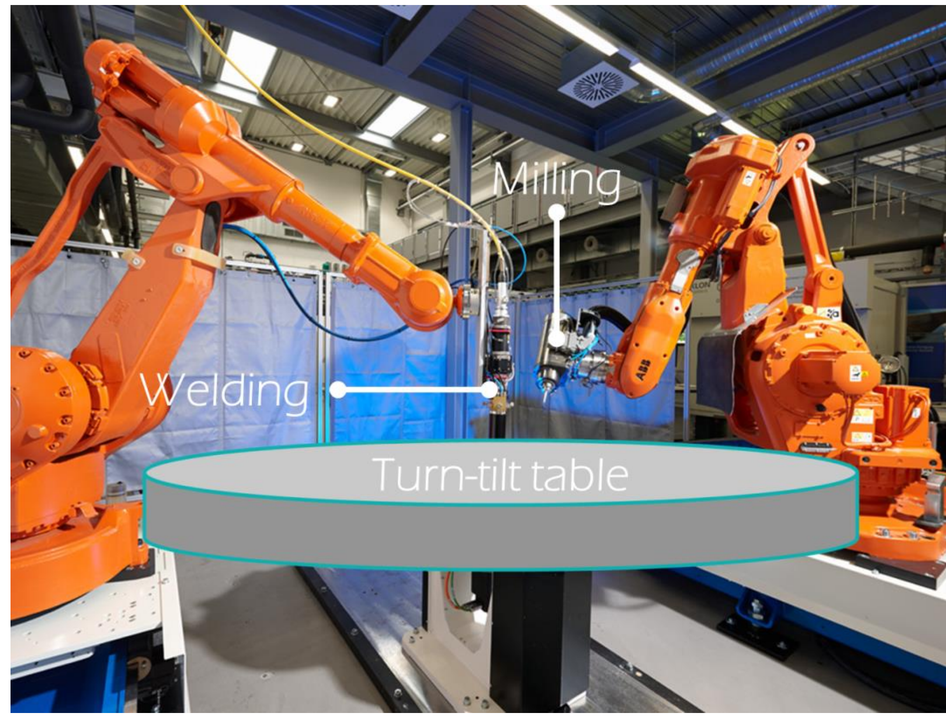


ATHENA optical bench with Additive Manufacturing

- **16 axis twin robot** system
- Turn-tilt table
- 1 robot performs **Additive Manufacturing** task
- 1 robot performs **milling** task

Fraunhofer IWS

AIRBUS DEFENCE & SPACE



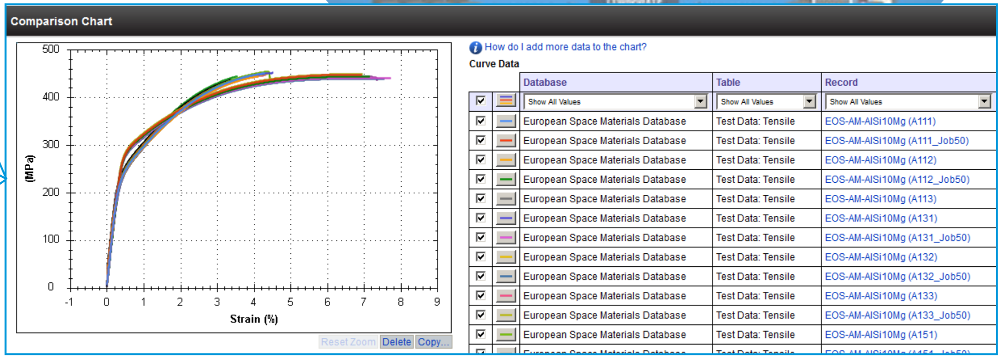
GRANTA MI: *European Space Materials Database*

<u>Individual Excel Importer Files for each Test:</u>
- **Tensile Test (under construction)**
- Fatigue Test
- Fatigue Crack Growth
- Fracture Toughness

<u>Include Media:</u>
- Pictures
- PDF files
- Hyperlinks

Automated Linking between The Database Tables

Report Example:



Status of the AM ECSS Proposal

1. **AIM G of the Roadmap:** Develop the required normative framework for AM made hardware (ECSS)
2. **Motivation:**
   - An ECSS standard is required which shall establish the processing and quality assurance requirements for space parts produced by Additive Manufacturing
   - Profiting of existing international standards (e.g. ISO, ASTM) for AM
3. **Status:**
   - In agreement with the ECSS TA a WG has been established
   - WG activity completed
   - ECSS WG recommended to be started in Q4 2017

EUROPEAN COOPERATION FOR SPACE STANDARDIZATION

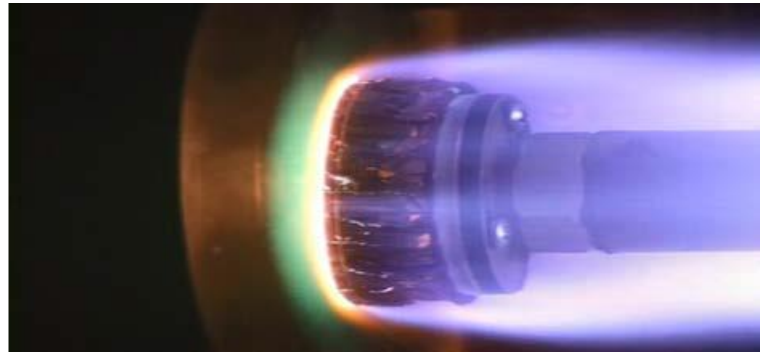
ASTM F42

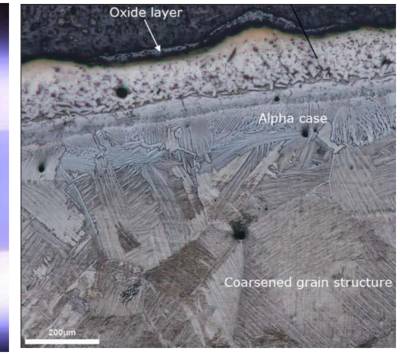
ISO/TC 261

The Problem – Space Debris

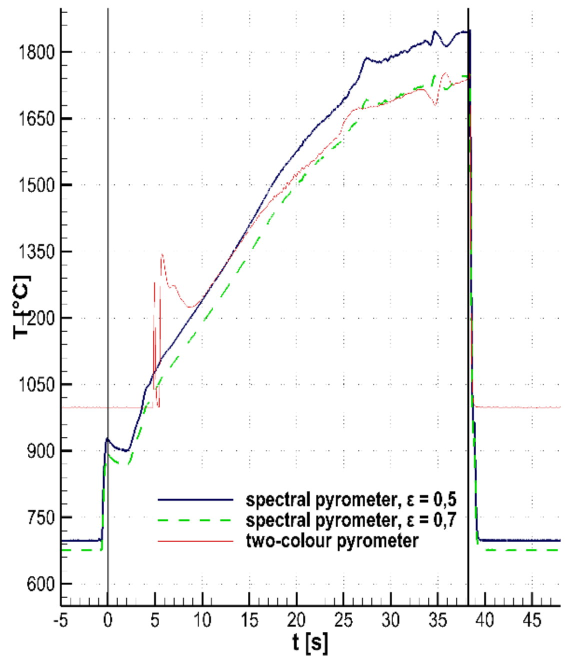
- LEO spacecraft and Launcher upper stages
- Orbital Decay at end of operating Life
- Uncontrolled re-entry in Earth Atmosphere
- Space Debris impacting ground
- Casualty Risk to be controlled

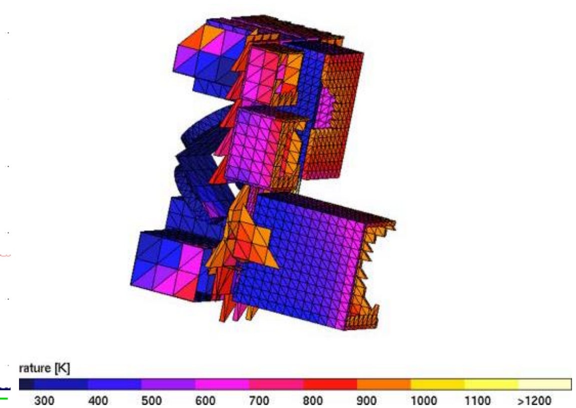
“Conscious” Fracture Mechanics of the System





- Multidisciplinary Approach
- Demisability: a new materials property
- Direct inputs for the re-entry simulation software
- Specific Heat Capacity, specific enthalpy, thermal expansion, density, thermal conductivity
- Leading to Design-for Demise





Thank you for your attention!

Would you like to know more?

Contact: Tommaso.Ghidini@esa.int