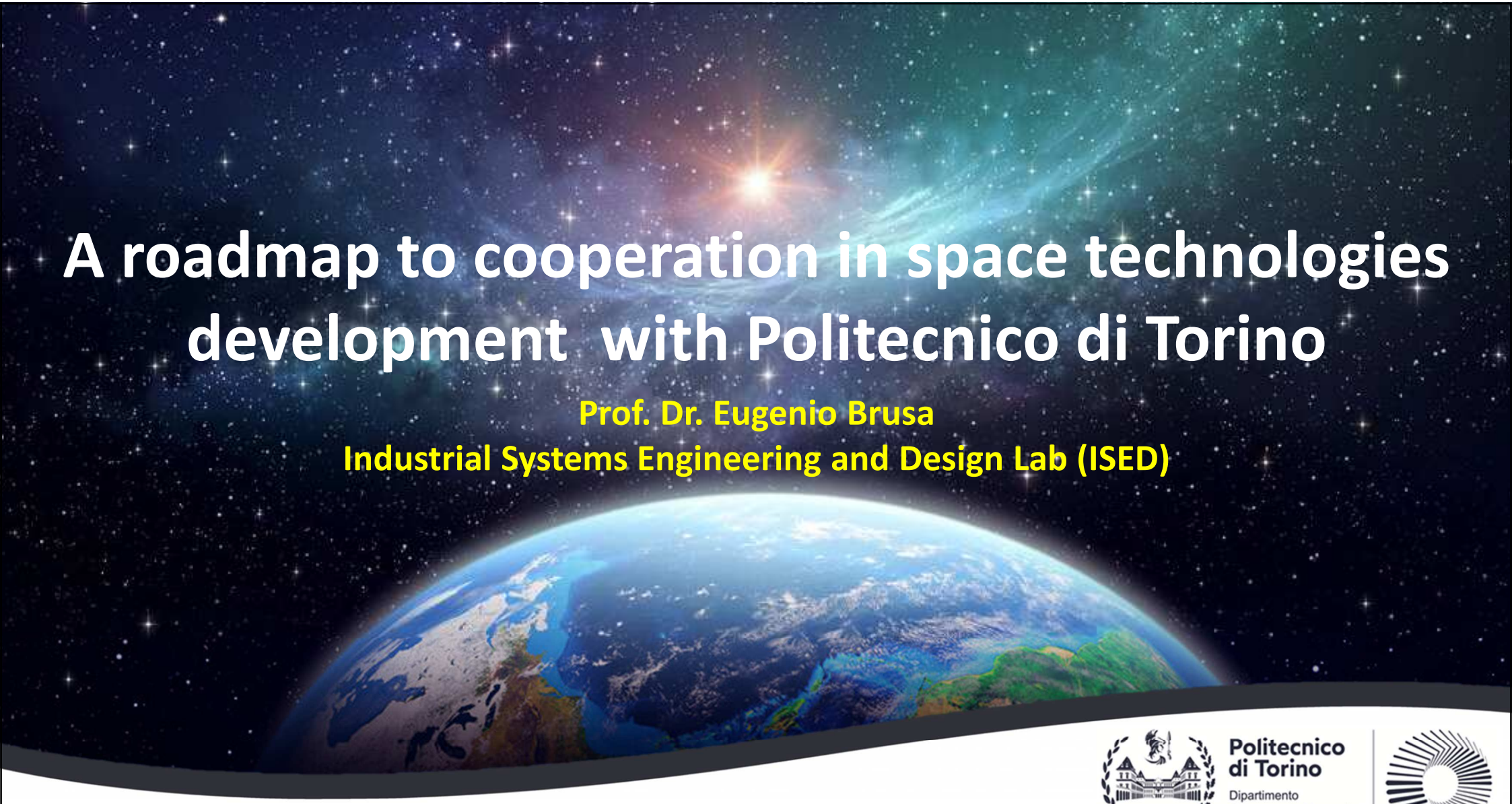
A roadmap to cooperation in space technologies development with Politecnico di Torino

Prof. Dr. Eugenio Brusa
Industrial Systems Engineering and Design Lab (ISED)



Politecnico di Torino
Dipartimento di Ingegneria Meccanica e Aerospaziale

Cooperation in the field of space technology development
Event organized by the Itaiian Embassy, Zagreb, December 11th 2025

Index of contents

- Context of space economy
- Research challenges and actions
- Cooperation leverages
- Conclusion

Context of space economy

- Current trends
- Technological needs

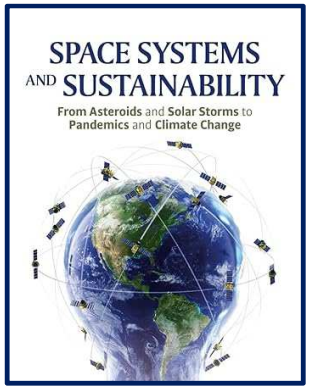
Where driving targets come from?

Current trends

- A **favourable context** in Europe to **Space Technology development** is clearly identified by several evidences…

The **EU Space**, AI and Cyber Resilience **Acts**

Planetary **defense and sustainability** tasks



Initiatives by the EU Agency for the Space Programme (EUSPA)

October 2025: announced "Bromo" Joint Venture as industrial pole of technology

Events… Dec 3, 2025 - Workshop "**Access to space and in-orbit operations: technologies and regulations for the next future**" at **European Parliament** (co-organized by the Politecnico di Torino)

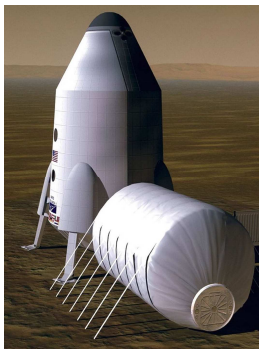
All those evidences define some **targets of sustainable actions** to drive activity of Academies and Industries

Current trends

- A **renaissance** is currently occurring for space technologies and related economy, as stated by the ***Euroconsult Space Economy report*** already in 2021, within **industry**, **connectivity**, **space data** and **space economy beneficiaries** for growth.

- Some **pillars** of space economy have been identified as (*S. Di Pippo, Space Economy, BUP, 2022*):

  - **Digital transition**: **satellites** constellation for communication services at terrestrial (<3.000 km), intermediate spatial (3.to8.000 km), spatial (8.to36.000 km) altitude; **cybersecurity**; **quantic entanglement**.



- **Green economy**: Earth **observation**, live monitoring, early warning of catastrophic events, agriculture **control**, climate change control…
- **Accessibility:** new and reusable **spacecrafts**, space **stations**, **habitats**, for exploration, tourism, research and science, **automation**, **robotics** …
- **Asteroids: mining**, exploration, **science**, Earth **defence**…
- **Planets exploration**: (Moon), Venus, Mars, and beyond to know our **solar system** …
- **Sustainability:** space **debris** removal, space **traffic** control, space **regulation** and law…
- **Life: manufacturing** into space, living and **biomedical** treatments, **working** in space…

… and even more

All those **comply with UN-SDGs**, **drive education** and **technological development** and motivate **research and innovation**.

Needs

That context motivates some **technological needs** in research & innovation as identified by **Space Agencies**, like the **ASI** (Italian), **ESA** (European, as in *"Future Space Missions and Services - A Road Map for Future Technology Development"*), and **NASA**… being currently developed in tight cooperation with **industries … and universities**

Needs

Public and application services:
- Weather
- Navigation
- Disaster management

Commercial services:
- Mobile telecom
- Multimedia
- Broadcasting
- Navigation and traffic
- Earth observation

Science and exploration:
- Astrophysics
- Planetology
- Moon/Mars/Other planets exploration
- Earth observation
- Microgravity

Space transportation:
- Reusable systems
- Small expendable launchers

Men and women in space:
- Space infrastructures
- Crew transportation and life
- Logistics, payload support

Drivers for technology R&D

- Satellites constellations
- Advanced computation and simulation
- Enabling technologies…

- End-to-end services
- Fully digital commercial services
- Interfaces between flying and ground systems and standards for communication
- On-board processing
- Higher frequency technologies
- Network of ground stations

- Advances in engineering technologies, smart and autonomous systems
- Missions success-oriented
- High man/machine interaction

- Cryo-propulsion
- Reusable systems
- Low cost technologies

- Dynamic design of product lifecycle based on data retrieving
- Reliability, Availability, Maintainability, Safety (RAMS)
- Human ability in space

Strategic technical domains

1. **Components/Materials**
2. **Solar Cells**
3. **Spacecraft Data Systems**
4. **Payload Data Processing**
5. **Antennas**
6. **Digital Telecommunications Payloads**
7. **Software Engineering**
8. **Space Environment / Robotics**
9. **Radar Technology**
10. **Thermal Control**
11. **High-Accuracy Pointing**
12. **Electric Propulsion**
13. **Micro-/Nano-Technologies**
14. **Systems Engineering**
15. **Sustainable Engineering**

Components, materials, technologies, and often subsystems are targets of interest

Specific areas of competence

Research challenges and actions

- Space mechatronics and micromechatronics
  - Science in space (satellite ASI/GG)
  - Walking in microgravity (ESA/AEVI)
  - Solar sail (U3P)
  - Venus exploration (JPL-NASA)
- Systems Engineering is key…
- Other activities in DIMEAS

Which technical contents are suitable for cooperation?

Politecnico di Torino
Dipartimento di Ingegneria Meccanica e Aerospaziale

Industrial Systems Engineering and Design Lab Dept. Mechanical and Aerospace Engineering Politecnico di Torino

ISED

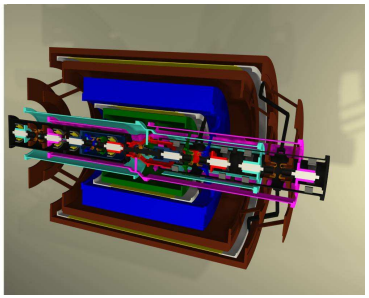
Space mechatronics and micromechatronics

Those **technological needs** require some research activities, even within the research group **ISED (Industrial Systems Engineering and Design)** at the **Dimeas/Politecnico di Torino**, among other ones, for instance [CHALLENGES]:

Strategic technical domains

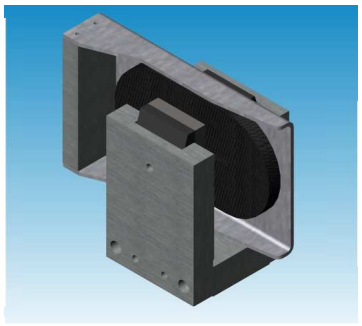
1. Components/Materials
2. Solar Cells
3. Spacecraft Data Systems
4. Payload Data Processing
5. Antennas
6. Digital Telecommunications Payloads
7. Software Engineering
8. Space Environment / Robotics
9. Radar Technology
10. Thermal Control
11. High-Accuracy Pointing
12. Electric Propulsion
13. Micro-/Nano-Technologies
14. Systems Engineering
15. Sustainable Engineering

SYSTEM SAFETY



ASI/GG - Satellite for Physics Experiments in space

MICROGRAVITY



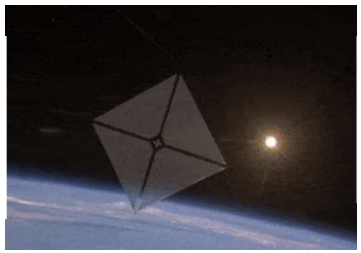
ESA/AEVI - Smart active magnetic suspension for microgravity

\+ MULTI-DISCIPLINARITY

HARSH ENVIRONMENT

JPL-NASA/Venus explorer with AM materials

SCALING



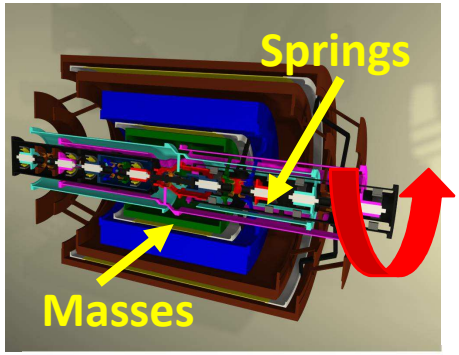
U3P/Solar sails

\+ COMPLEXITY

Key issues

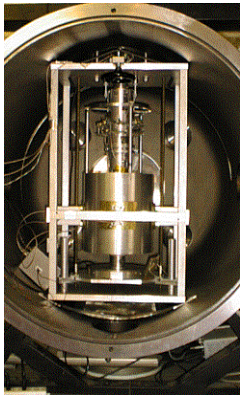
1. Cross – fertilization between domains
2. Acceleration of technological evolution
3. Driving effects for the research activity
4. 'Glocalization' as a key factor for success
5. Urgent need for a holistic approach to design (e.g. Systems Engineering)

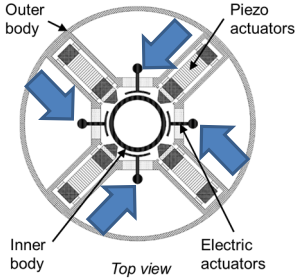
Science in space (satellite ASI/GG)



GG - Satellite for Physics Experiments in Space

This experiment (diameter 100 cm, length 70 cm, 150 kg, rotating at 5 Hz, altitude 520 km) was conceived in early 2000's to investigate gravity fundamentals: **do equal cylindrical masses (10 kg) made of different materials fly in geostationary orbit at either equal or different distance from Earth?**

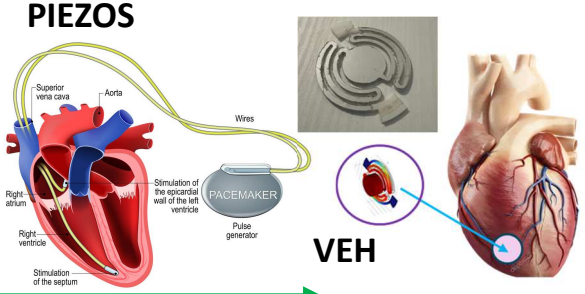




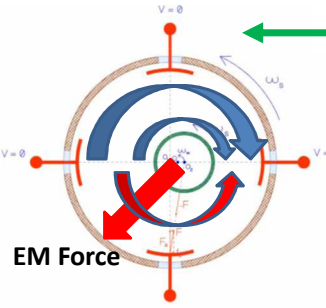
Challenges

1. To **block masses** during launch and then **release**
2. To **damp unstable whirling motion** of rotors, **without a stator** (non rotating)
3. **To measure very small displacements** of masses

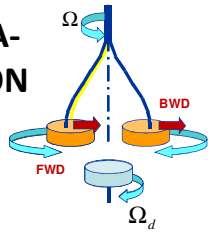
PIEZOS

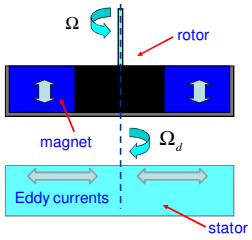


VEH



CONTRA-ROTATION





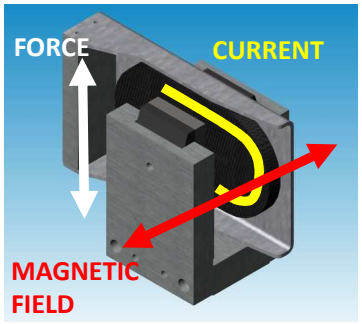
Solutions

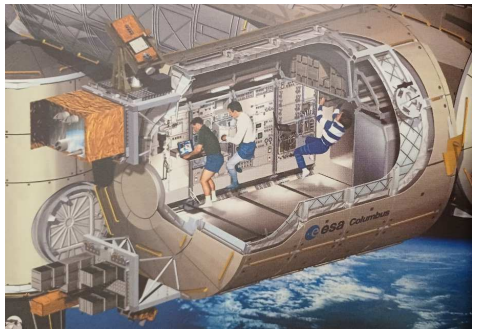
1. **Piezo-actuators** strain is **actively controlled by electric field** to block masses and then fast release
2. Whirl damping is provided by **capacitive self-sensing actuators**, **measuring mass** displacement
3. Electric field fed to actuators **rotates in opposite direction** to make control effective and avoid synchronization

Follow-up (cross-fertilisation; speed-up)

- ❑ Piezoelectric transducers are applied to **vibration energy harvesting (VEH)** in autonomous paediatric pacemaker
- ❑ The **contra-rotating damping (patent)** is used in magnetic dampers, based on eddy currents (automotive, industry…)

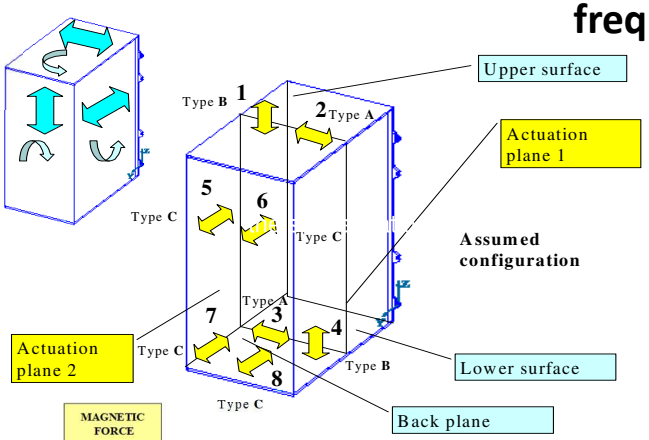
Walking in microgravity (ESA/AEVI)

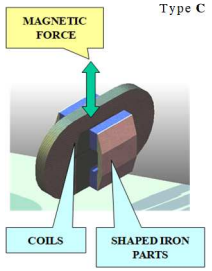




Smart active magnetic suspension for microgravity

When operating on the ISS, astronauts walk along the ISS modules and thus experiments within racks suffer effects of vibration, to be uncoupled from the tests and damped, through a contactless suspension system.





AMD

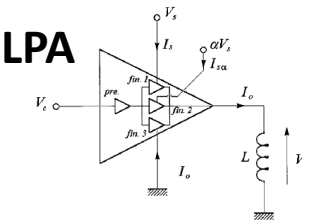
Challenges

1. To **isolate tests** from environmental vibration
2. Applying **contactless actuators with large gap**
3. Operating at **low frequency**

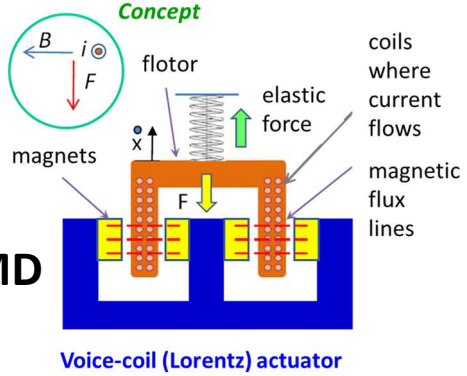
Solution

1. **Active Magnetic Dampers** are based on the Lorentz's force (variable current flows within magnetic field and force acts along orthogonal direction)
2. Power to coil is supplied by a **Switching Linear Power Amplifier** (more gates for different power values)

SLPA



Concept

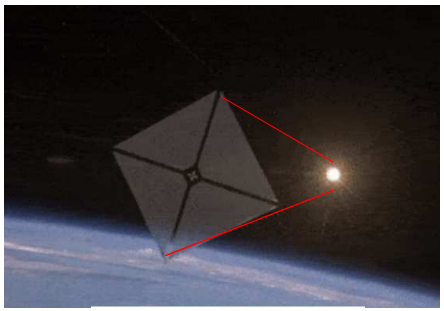


Voice-coil (Lorentz) actuator

Follow-up (tech speed-up)

- ❑ **AMD:** The **Lorentz's magnetic actuator** is widely used in mechatronics (large gap between moveable parts)
- ❑ **SLPA:** The **switching linear power amplifier** has been developed for the active magnetic bearing technology (higher efficiency)

Solar sail (U3P)



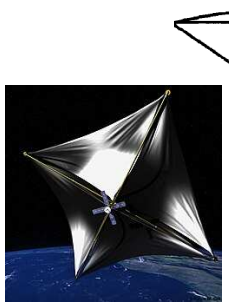
Light solar sail

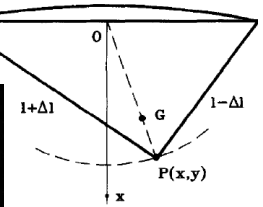
The Aurora solar sail (**Prof. G. Genta**) is propelled by photonic pressure (1.52 10^{-4} Pa at 0.245 AU), is a **130 kg spacecraft (5 payload, 80 mass, plus other systems) includes a 250 m side and 0.2 um thick sail in aluminium, covered by chromium, and carbon fibres composites booms and masts to be polymerised into space.** Critical thermal effect results in a difference of 50°C more in sail than in structure at perihelium.

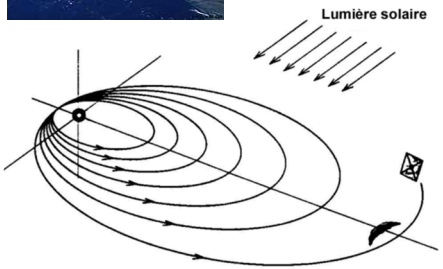
Challenges

1. To **predict numerically** stress and strain in such large and extremely thin structure
2. To demonstrate **feasibility of polymerisation** in space
3. To **manufacture** the whole system

ORIGINAL CONCEPT

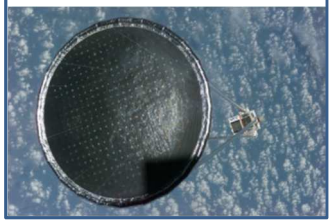






Today…

Courtesy NASA Langley Res. Center 2024



Solutions

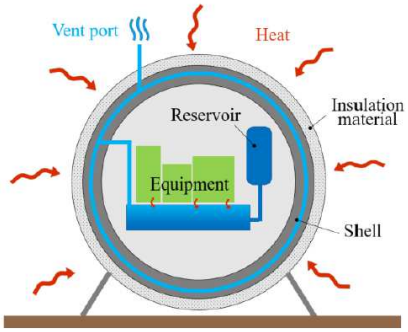
1. A **numerical procedure** has been expressively set up (not commercial software)
2. The **industrial partner** identified the process for manufacturing the sail
3. Polymerisation in space supported by **inflation of flexible elements**

Follow-up (precursor project)

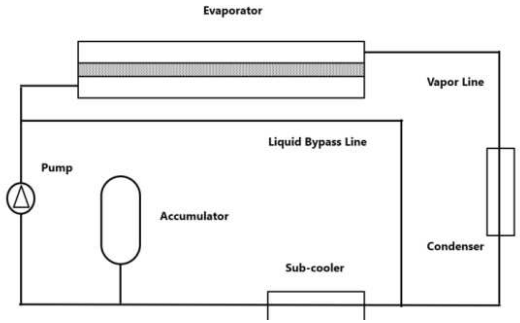
- ❑ Some **computational tools** were introduced to analyse the sail membrane
- ❑ Studies on **compact deployers, parachute sail with inflatable booms,** and **polymerization in space** started…
- ❑ It excited use of the **mini-satellite technology** to deployment…
- ❑ Years after, technology met concepts in the *Breakthrough Starshot (Dr. S. Hawking)…*

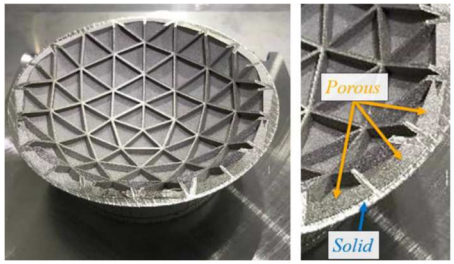
Venus exploration (JPL-NASA)

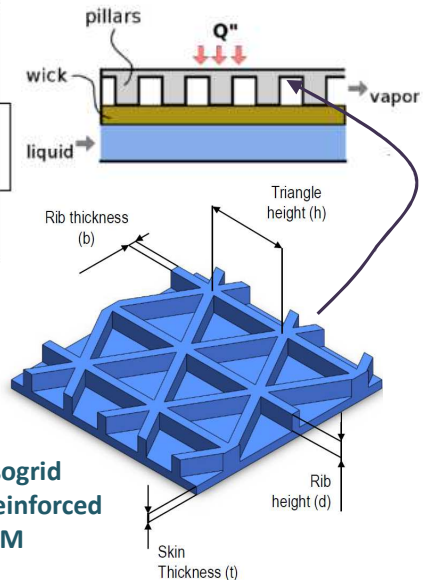
Jet Propulsion Laboratory
California Institute of Technology



Venus explorer







Isogrid reinforced AM

A spherical probe (1.12 m diameter) with AM structure in Ti6Al4V with solid skin and porous inner wall is conceived **to isolate inner bay at 70°C for 24 h, to cope with limitations induced by carbon dioxide gas with sulfuric acid, wind (360 km/h), surface pressure (93 bar), temperature (462 °C)**

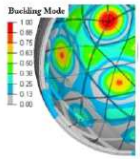
Challenges

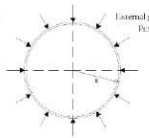
1. To **design a lightweight system** despite the harsh environmental conditions
2. **To prevent collapse** under compression (**buckling**)
3. To perform **structural calculation in nonlinear behaviour** with **AM materials**, thermal effects, process uncertainties
4. To perform **physical validation** of system

Solution

1. The heat exchange solution conceived by JPL for cooling the bay is associated to **Isogrid reinforced AM** structure
2. Computations are based on **analytical (sizing)** and **numerical (detailed design, Finite Element Method)** modelling with **optimization of the thermal-fluidic-structural problem**
3. Validation is performed at large testing facilities in **San Diego** to **test the probe collapse**

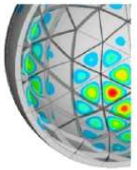
Venus exploration (JPL-NASA)

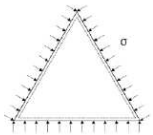




General Instability

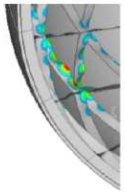
$$p_{GI} = c_0 2E\frac{t^2}{R^2}\beta$$





Skin Buckling

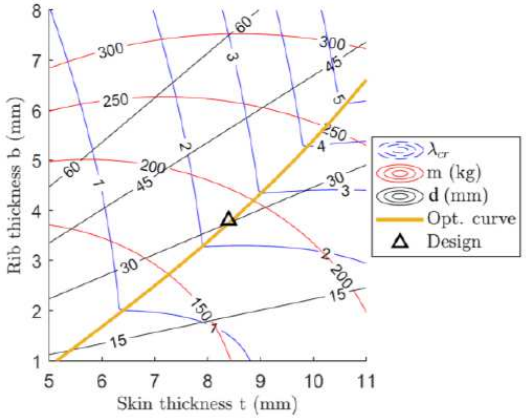
$$p_{SB} = c_1 2E\frac{t(1+\alpha)}{R}\frac{t^2}{h^2}$$



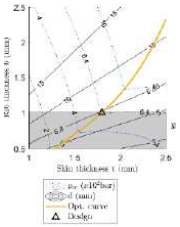
Rib Crippling

$$\sigma \quad p_{RC} = c_2 2E\frac{t(1+\alpha)}{R}\frac{b^2}{d^2}$$

COLLAPSES

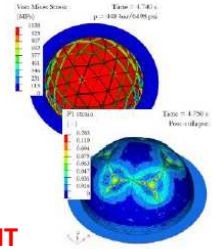


OPTIMISATION



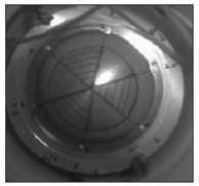
DESIGN

A Ø20 cm sphere is designed according to the analytical method



FEA

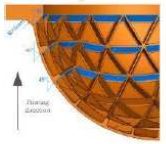
The structural behavior is investigated using linear non-linear simulations



TESTING

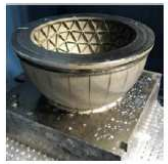
DEVELOPMENT

V&V



REFINEMENT

Chamfers and fillets are added, to improve the manufacturability

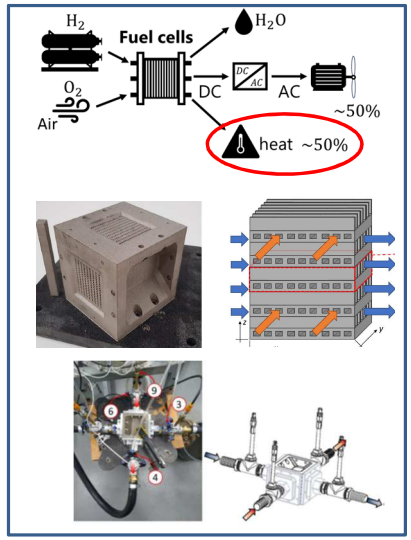


MANUFACTURING

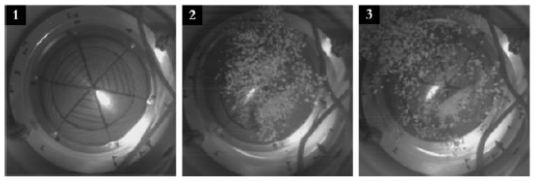
Several domes are built in Ti6Al4V using DMLS. After Heat Treatments, supports are removed by machining.

Follow-up (cross-fertilisation; speed-up)

- The proposed solution looks reliable and identifies the **design and V&V processes**
- The **optimization process** is generalized to design **domes for habitats, aeronautical and automotive systems**
- Integration of subsystems requires a **holistic approach to design** as the **Systems Engineering**



TMS for aircraft / motor vehicle



Hydrostatic test (Exp: 410.3 ± 4.0 bar vs Numerical 410 bar)

Long term thermal test: survived

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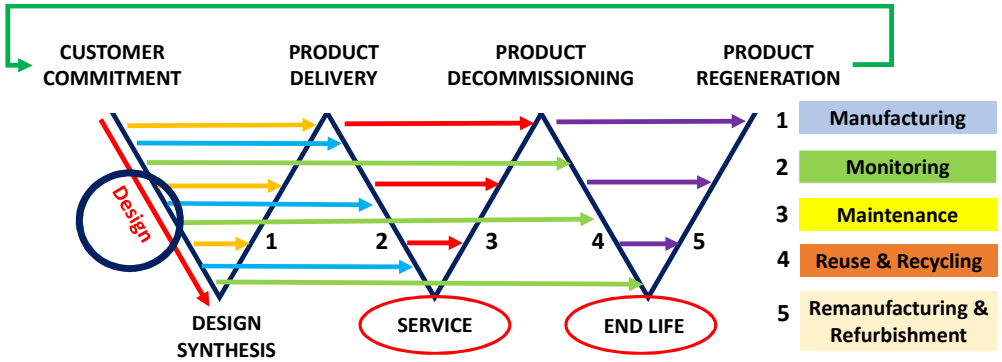
Department of Mechanical and Aerospace Engineering - DIMEAS
Prof. Dr. Eugenio Brusa

Systems Engineering is key…

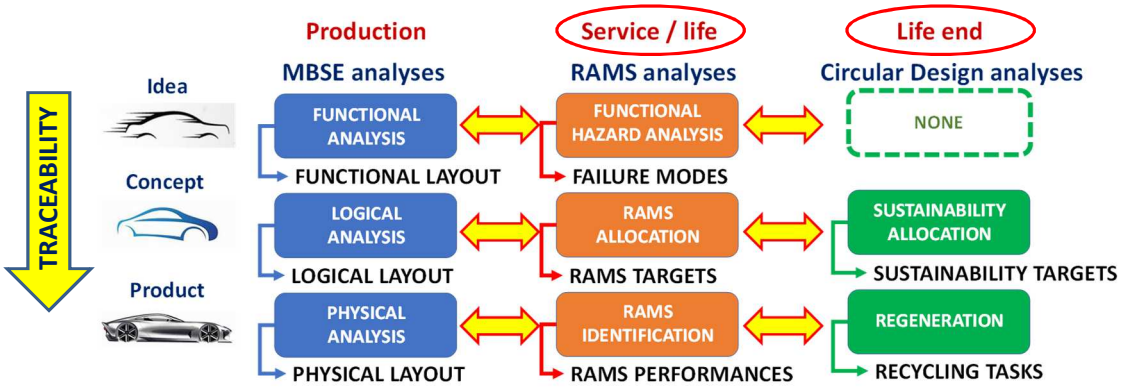
All those experiences demonstrate that **a holistic approach being able to take care of all the design issues and of the overall system complexity is strictly needed**, and motivates both **educational paths and research activity** within the **Systems Engineering Methodology** [ref. IEC/IEEE and INCOSE standards]. Briefly, it applies: …

1. Systematic **PROCESS** to design, which looks to **manufacturing**, **operation** and **decommissioning**, to enhance **Reliability, Availability, Maintainability, Safety (RAMS)** and Sustainability by the **Life Cycle Assessment (LCA)…**

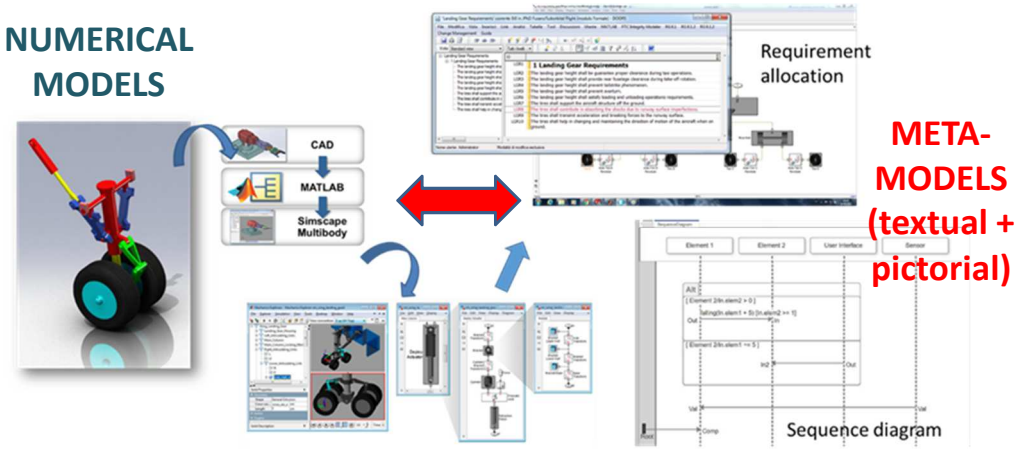


PRODUCT LIFE CYCLE DEVELOPMENT (MULTIPLE «V» DIAGRAM)

2. **TRACEABILITY** from **customer needs** to system **requirements** -> -> **functions** -> **logical components** -> **built parts**



3. **INTEROPERABILITY** between ***qualitative 'functional' models' (SysML meta-language)*** and ***quantitative 'physical models' (numerical)***



Other activities at DIMEAS…

Politecnico di Torino
Dipartimento di Ingegneria Meccanica e Aerospaziale

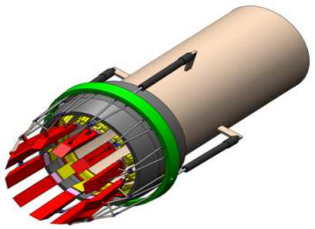
Among activities promoted by **other Research Groups** many are contributing to the above mentioned tasks.

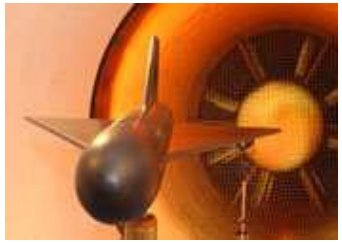
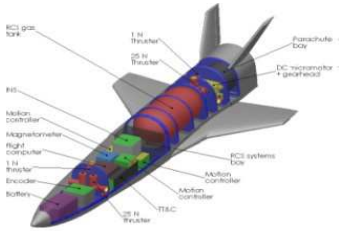
Space technology

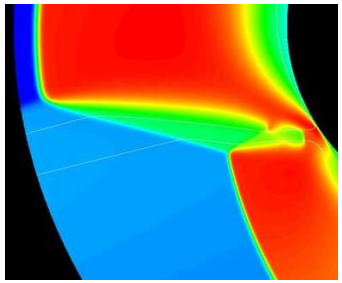
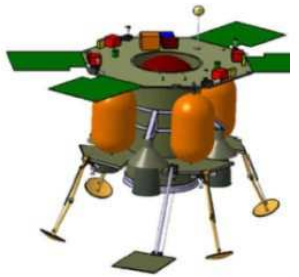
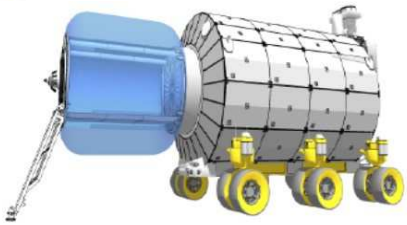
- Space structures
- Mission analysis
- Spaceflight dynamics
- System engineering
- Cubesats
- Habitats

Aerospace propulsion

- Transmissions
- Prognostic techniques
- Gasdynamics

Theoretical, computational and experimental methods are applied

Cooperation leverages

- Local ecosystem at PoliTo
- Territorial ecosystem
- European university alliances
- The ISSNAF mentoring and international networks
- Roadmap for an agile cooperation

What kind of approaches could be exploited to cooperate within the Space Economic ecosystem ?

Local ecosystem at PoliTo

To cope with those needs the Politecnico di Torino operates as academic ecosystem including **Research Groups (researchers, professors, PhD candidates and Labs)**, belonging **Departments**, somehow aggregated by **thematic targets** into some **Interdepartmental Centres (several departments cooperating) in a sort of matrix organisation (centres vs departments).** Many of those deal with Space technologies in their activities.

Centres

DENERG _ Department of Energy "Galileo Ferraris"
DIMEAS _ Department of Mechanical and Aerospace Engineering
DISAT _ Department of Applied Science and Technology

Industrial Engineering Area

Information Technologies Area

DAUIN _ Department of Control and Computer Engineering
DET _ Department of Electronics and Telecommunications

DIGEP _ Department of Management and Production Engineering
DISMA _ Department of Math, Sciences "Giuseppe Luigi Lagrange"

Engineering and Management and Mathematics for Engineering Area

Civil and Environmental Engineering, Architecture, Urban Planning and Design Area

DAD _ Department of Architecture and Design
DIATI _ Department of Environment, Land and Infrastructure Engineering
DISEG _ Department of Structural, Geotechnical and Building Engineering
DIST _ Interuniversity Department of Regional and Urban Studies and Planning

Departments

Research Groups and Laboratories

Groups at DIMEAS

The **Dept. Mech. and Aer. Eng.** includes several research groups, as well as it happens in other depts.

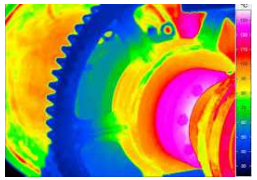
Aircraft modelling simulation and control

Flow control and aeroacoustics

Gas turbine and compressor blades

Aerospace propulsion

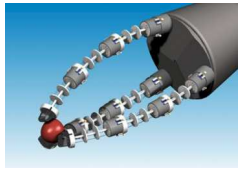
Aircraft Structural Design



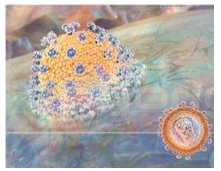
Design of drive components and thermography

Design of aircraft and composite structures

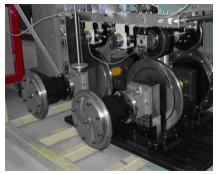
Additive manufacturing for Aerospace



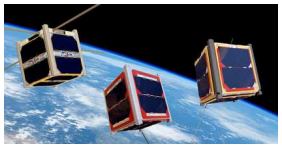
Automation and robotics



Bio-inside Lab



Design of railways systens and MEMS

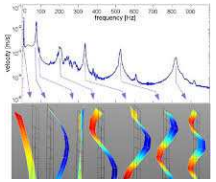


Design of aerospace systems

History of technology

Mechanics of materials and joints

Design of rotors and mechatronic systems



Dynamics of mechanical systems

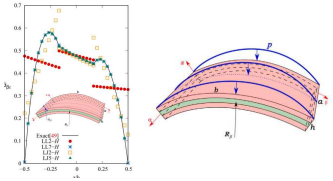
Dynamics, control and flight simulation

Electric and Hybrid Vehicles

Ergonomics

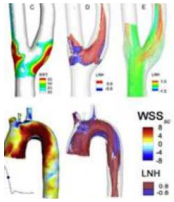
Industrial Systems Engineering and Design

Mechatronics and servosystems



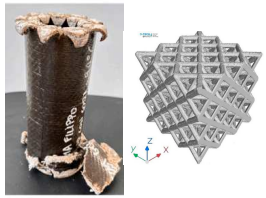
Multi-layered structures and multi-field analyses

Smart Structures and Systems



Solid and fluid biomechanics

Vehicle dynamics



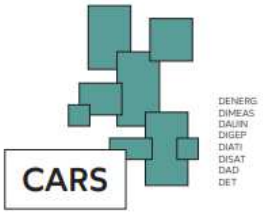
Vehicle structure and safety

Centres

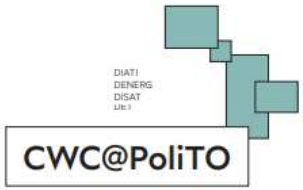
The **Interdepartmental Centers** cover several **strategic topics** and operate along **a transversal direction to departments**, while research groups support these initiatives.

In 2025, a **new Centre** has been constituted to make affordable the action specifically applied to **space tech development:**

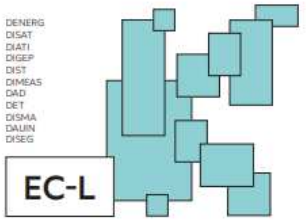
IDEAS – Integrated Digital and Experimental Aerospace for Sustainability



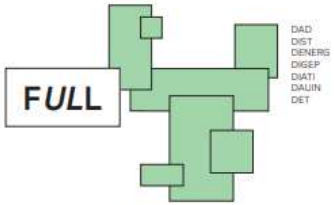
Sustainable Mobility



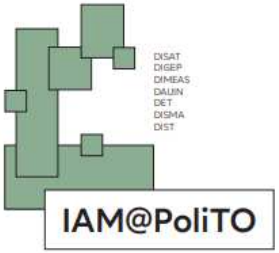
Clean Water



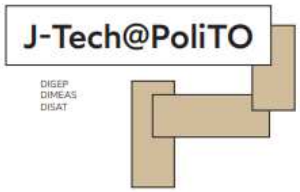
Clean Energy



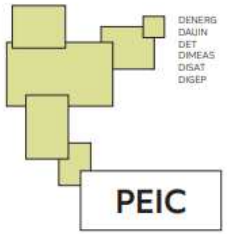
Future of Urban Development



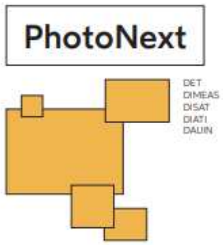
Additive Manufacturing



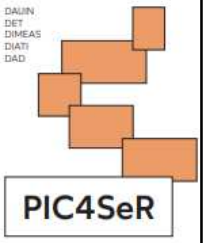
Joining Systems and technologies



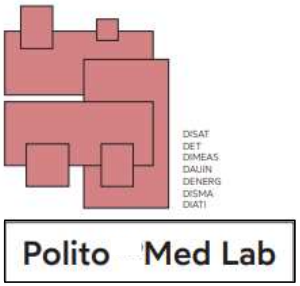
Power Electronics



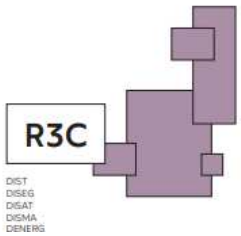
Photonics



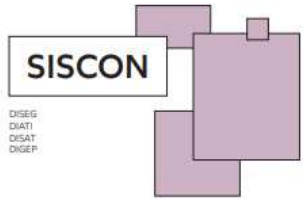
Robotics for Service



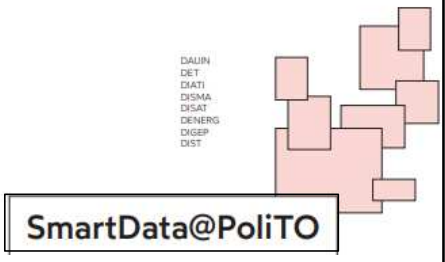
Bioengineering and Medicine



Risk assessment



Safety of infrastructures



Big data vs Data Science

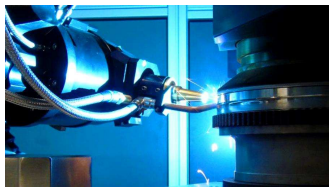
Territorial ecosystem

Regional platforms (cooperation between SML/E & Research Bodies)

Smart factory

Health an wellbeing

Bio and circular economy



Intelligent technological supply chain

1 National Technologic Cluster on Aerospace (CTNA)

13 National technological districts

- Lombardia – Aerospace Cluster
- **Piemonte – Aerospace district**
- Liguria – Integrated intelligent systems
- Veneto – Space Consortium
- Emilia Romagna – Aerospace Cluster
- Toscana – Aerospace district
- Umbria – Aerospace cluster
- Abruzzo – ICT and Aerospace
- Lazio – Innova (including Telespazio)
- Puglia – Aerospace district
- Basilicata – Aerospace cluster
- Campania – Aerospace district
- Sardegna – Aerospace district

1 National Space Agency

More than 220 Companies active within space technologies

National Recovery Resilience Plan

The **European Resilience and Recovery Plan** funded several activities and a temporary consortium for fostering innovation in space technology called **“Space It Up!”** was constituted.

It is even connected to ***National Phd programme in Space Technology***

SPACE IT UP!

21 Companies and Research Centres and Institutes and 12 Universities

PhD SST Space Science and Technology

National Doctorate in Space and Technology

1. It identifies **current research and innovation areas** within cooperation between companies and academies
2. It provides a **framework of interaction**
3. It is a **temporary action**, while Territorial ecosystem is going to be stabilized

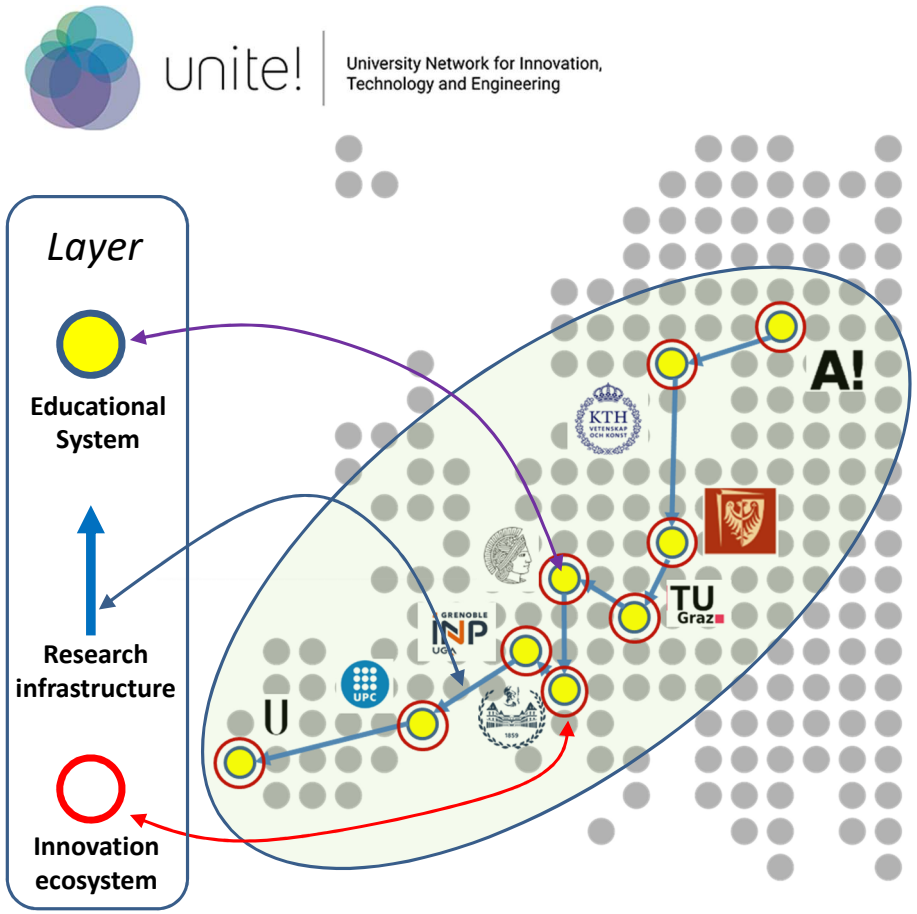
European university alliances

1. The **EU Commission** promotes cooperation between countries. Partner Universities actuate **joint actions** within **Education**, **Research** and **Innovation,** as the **"Unite!" Alliance** (9 partners)

2. **Education: joint degrees, virtual and physical mobility,** common **on-line courses** (BSc, MSc, PhD). A federation of graduate schools was constituted **(UDS - Unite Doctoral School)** and PhD programmes cooperate through the **Academic boards** (AI, IND 4.0, **Space Tech**….)

3. **Research:** universities are **nodes of a network,** share **infrastructures** and collaborate in **doctoral education. Thematic communities** collect researchers and professionals from ecosystems (**Cubesats, Space flight, Systems Eng.** etc).

4. **Innovation:** universities are **hubs of knowledge** and interact with local **ecosystems** (companies, industries, … stakeholders) and compose the **ecosystem.**



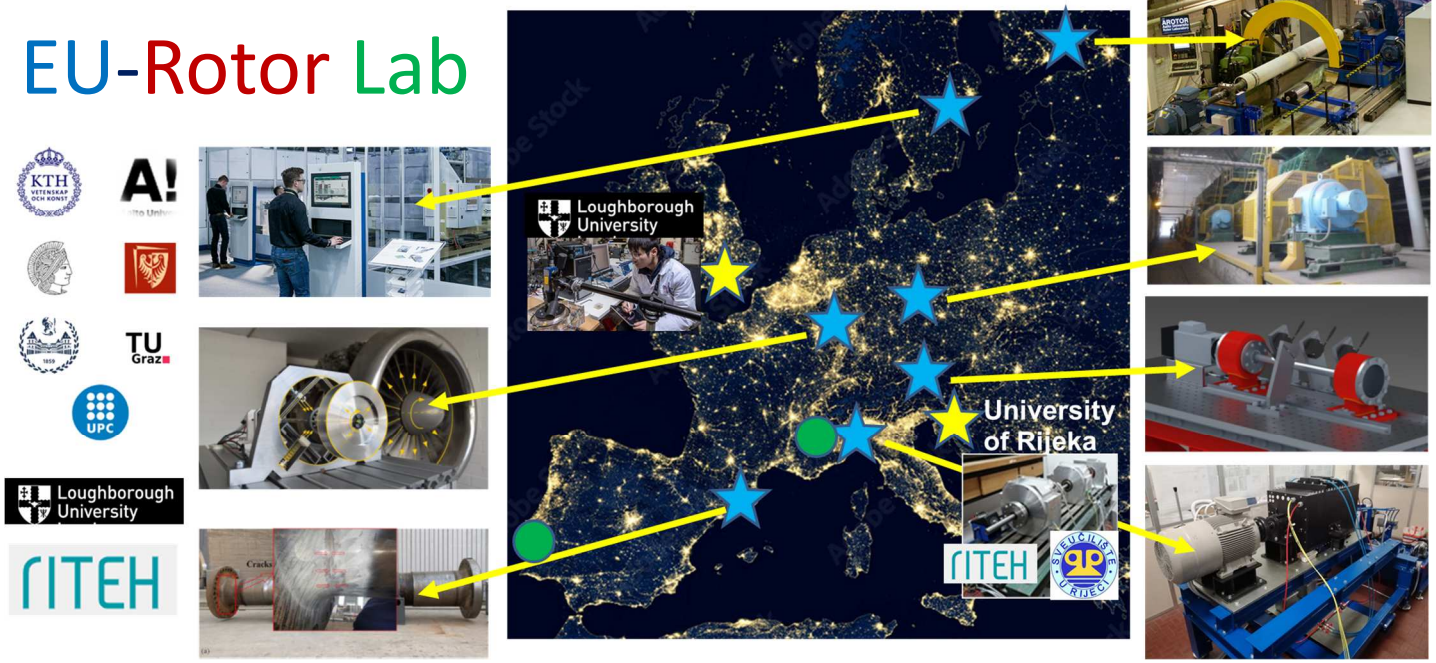
DOCTORAL EDUCATION IS EXPLOITED AS A GATE TO CONNECT RESEARCH AND INNOVATION THROUGH THE ALLIANCE

The Unite! networking mechanism

unite! University Network for Innovation, Technology and Engineering

- Several **PhD programmes** contribute to an **Academic Board** (e.g. **Industry 4.0**) managing **Education** (e.g. summer schools, co-tutelles, …)
- Researchers of "Unite!" experts in given specific field set up some **networks of Labs,** namely **Thematic Communities,** supporting **Research** activities and projects, contacts with stakeholders, and sharing their infrastructures…
- Actors of **local ecosystems** contribute directly to **Thematic Communities** and promote **Innovation.**

EU-Rotor Lab



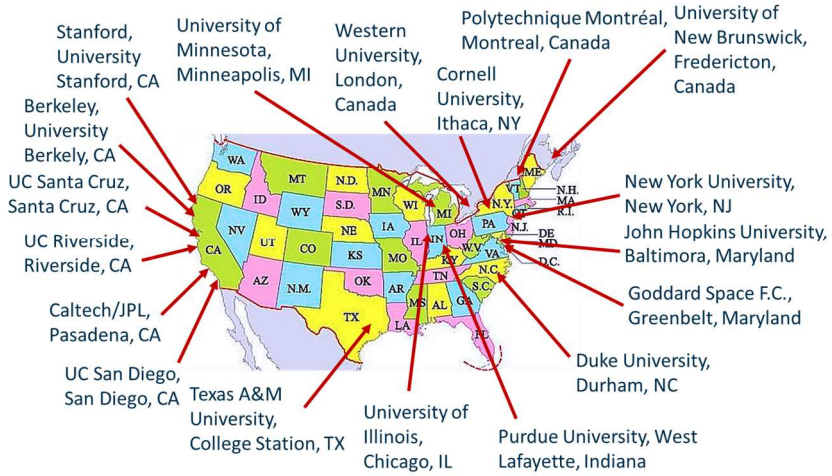
Example: **EU-Rotor Lab is** a **network of specialists in rotating systems, design and condition monitoring,** a **Thematic Community,** connecting specialized Labs within **Unite!,** and includes two **Associate Labs** as the **Univ. Loughborough (Dynamics Lab)** and **Univ. Rijeka (RITEH, Mech. Eng.)**.

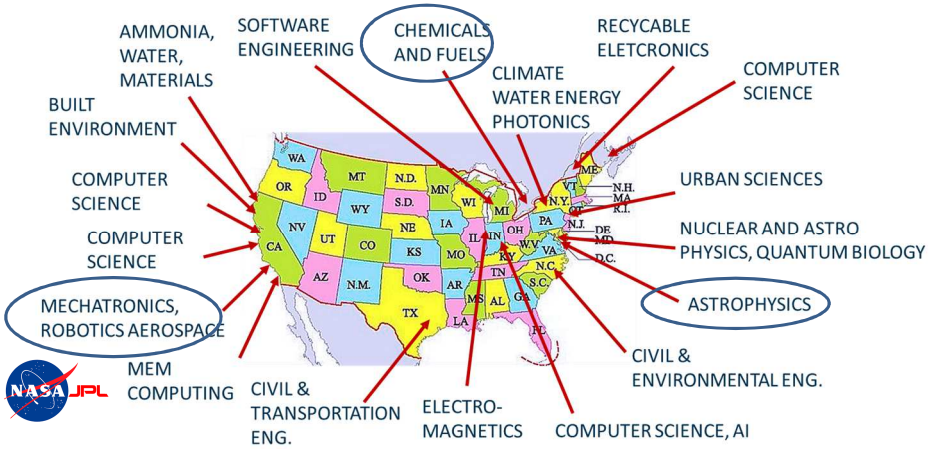
The ISSNAF mentoring and international networks

ISSNAF
ITALIAN SCIENTISTS & SCHOLARS IN NORTH AMERICA FOUNDATION

MUR
Ministero dell'Università e della Ricerca

Collaboration with the **ecosystem of North America** is even promoted by the partnership with the **ISSNAF** based upon an action of ***mentoring of PhD students*** towards universities and research centres (e.g. JPL) for mobility, supporting ***networking*** even through a new ***database*** of R&I



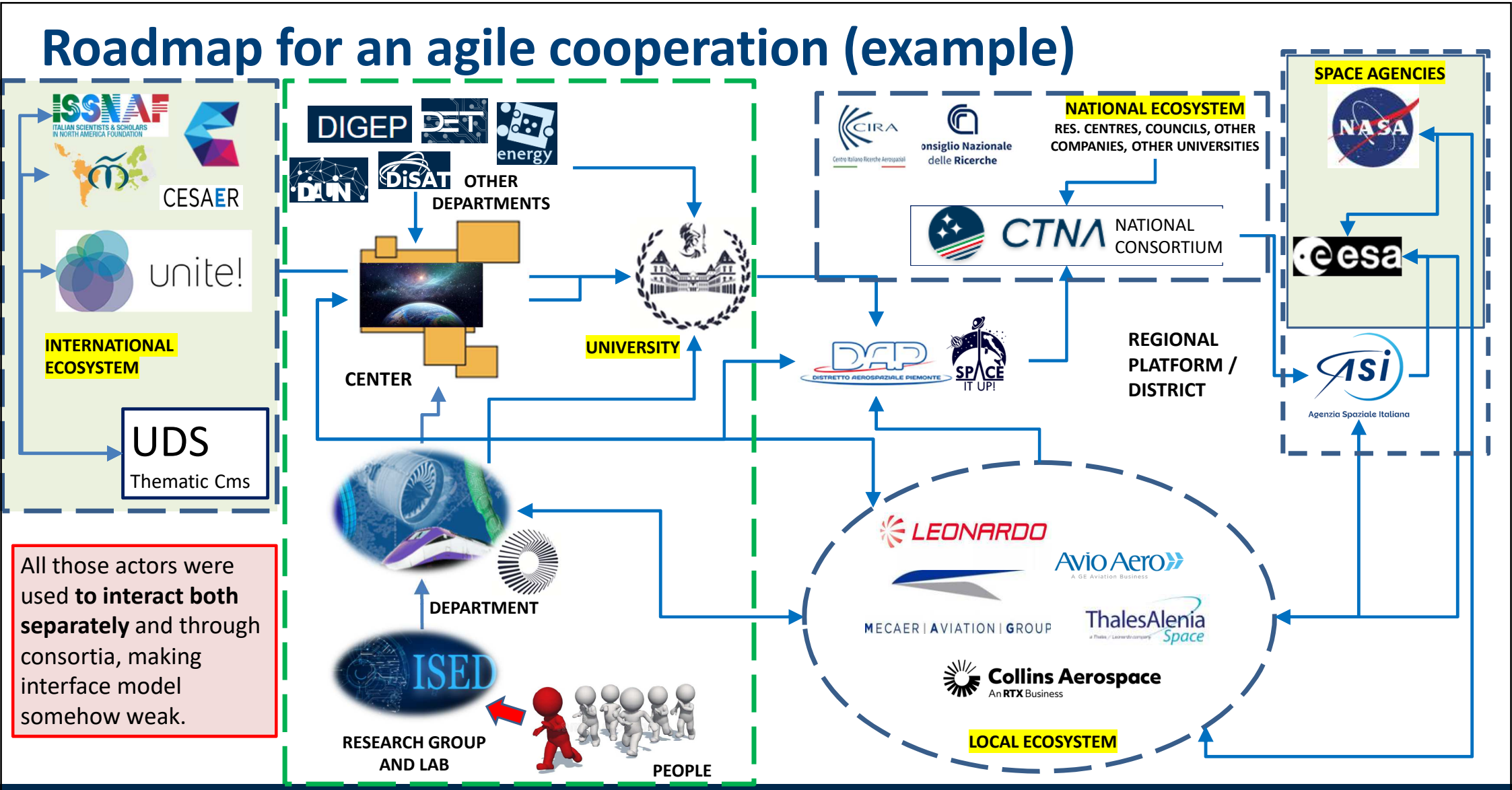


CESAER

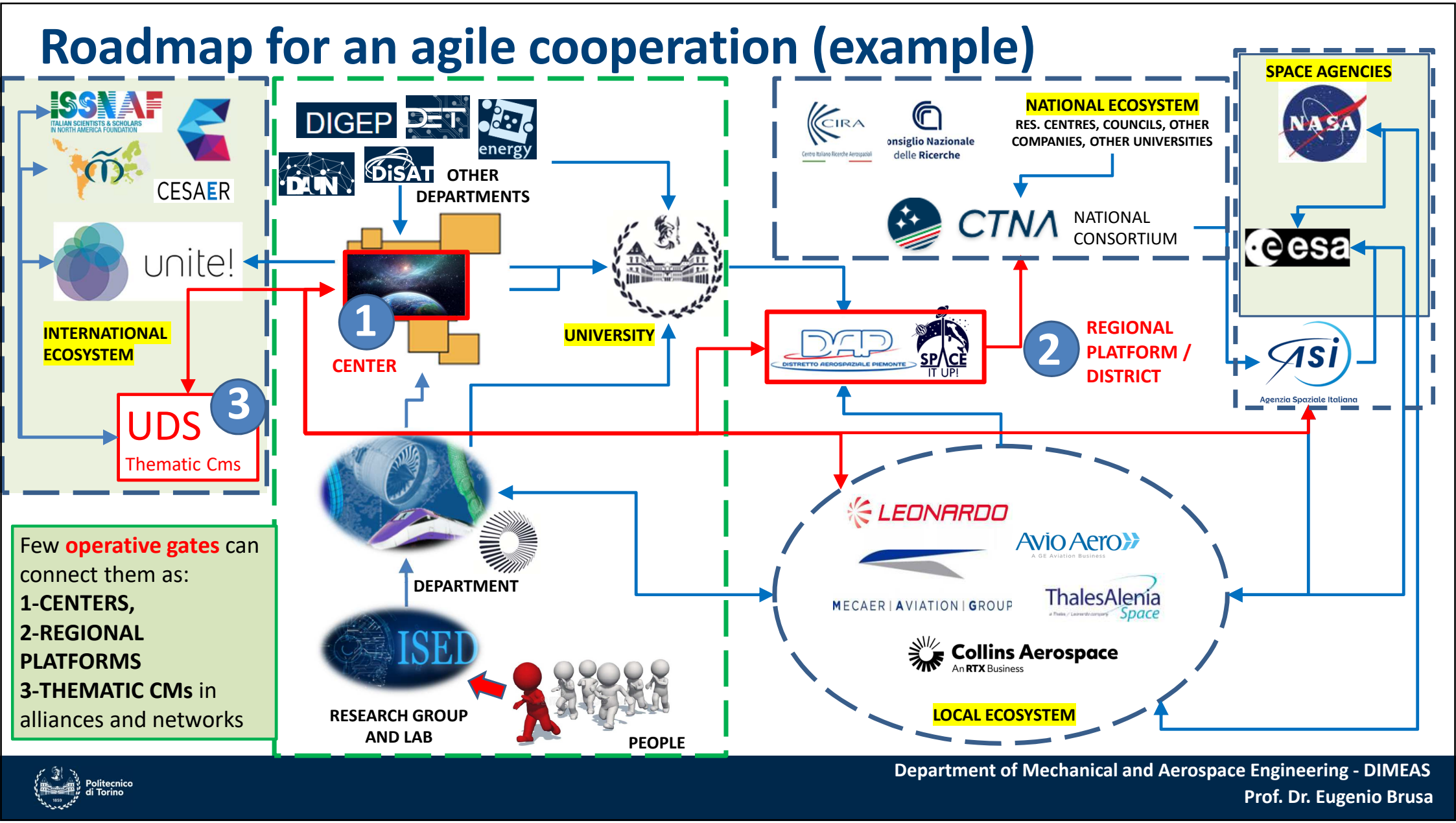
Collaboration with the **ecosystem of South America** is supported by the **MAGALHÃES NETWORK** (20 European + 20 Latin American Universities)

In addition, action is strengthened through the **CLUSTER** (Consortium Linking Universities of Science and Technology for Education and Research) and **CESAER** (association of leading universities with a strong science and technology profile)

Roadmap for an agile cooperation (example)



Roadmap for an agile cooperation (example)



Few **operative gates** can connect them as:
1-CENTERS,
2-REGIONAL PLATFORMS
3-THEMATIC CMs in alliances and networks

Conclusion

1. Current strategic targets of Space Technology development are identified by Space Agencies and Stakeholders, as key actors of ecosystem, driving the research activity and innovation and often funding activities.
2. Some key features of Space Systems design as harsh environment, scaling, multi-disciplinarity, critical safety and stability, operation in microgravity, sustainability… require disruptive solutions and new educational systems, but assure a good cross-fertilization to other technical domains.
3. A key role in cooperation is played by consortia at Local, National and International levels. Academy supports cooperation through networks and alliances even exploiting the Doctoral Education to create ecosystems and to train young generations within Space Technology.

Acknowledgment

ASI AGENZIA SPAZIALE ITALIANA
esa
LEONARDO
U3P
NASA Jet Propulsion Laboratory California Institute of Technology
UNIVERSITY OF BATH
unite!

unite! | University Network for Innovation, Technology and Engineering

Thank You for Your kind attention

Thanks to Italian Embassy in Croatia for this kind invitation and to University of Zagreb, FER, for hosting this event

Prof. Dr. Eugenio Brusa

Professor of Machine Design

Rector's advisor for the internationalisation of doctoral education

Coordinator of the Unite! Doctoral School of the European Alliance "Unite!"

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Politecnico di Torino
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