LEIDEN, NETHERLANDS - DECEMBER 2015

THE FUTURE OF ISS UTILIZATION: AN INDUSTRY PERSPECTIVE

NANORACKS

BLUE ORIGIN

AIRBUS DEFENCE & SPACE

#FUTUREISS

Testing Urea Fuel Cells for Applications in Manned Outer Space Missions

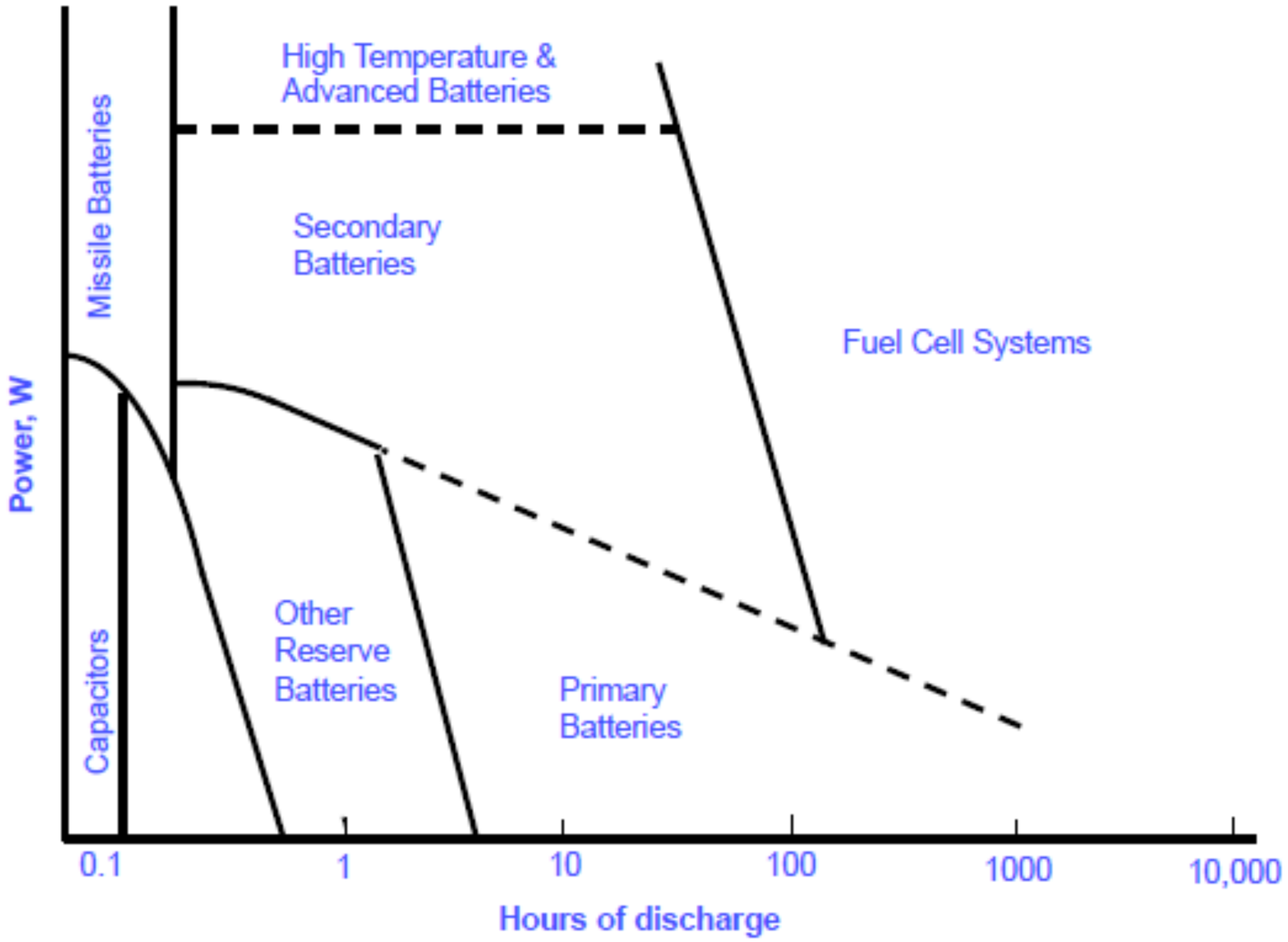
Dumitru-Dorin PRUNARIU

Romanian Space Agency - ROSA

Outline

1. **Fuel Cells and Space Applications**
2. **Advanced materials and energy storage systems**
3. **Urea Fuel Cell Concept**
4. **FCtoOutSpace Project**
5. **Conclusions**

Energy Storage



Requirements

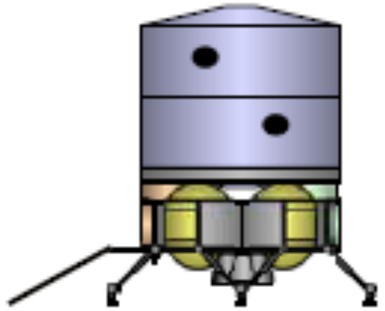
- High power density and high efficiency fuel cell stack;
- Long life (5000 hours), maintenance-free operation;
- Passive “balance of plant” components to decrease power use
- Increase the reliability and fault tolerance of fuel cells system without adding redundancy;
- Passive dissolved gas removal from water.

Applications

Un Pressurized Rover
(1-2 kW, 1-5 kWh)

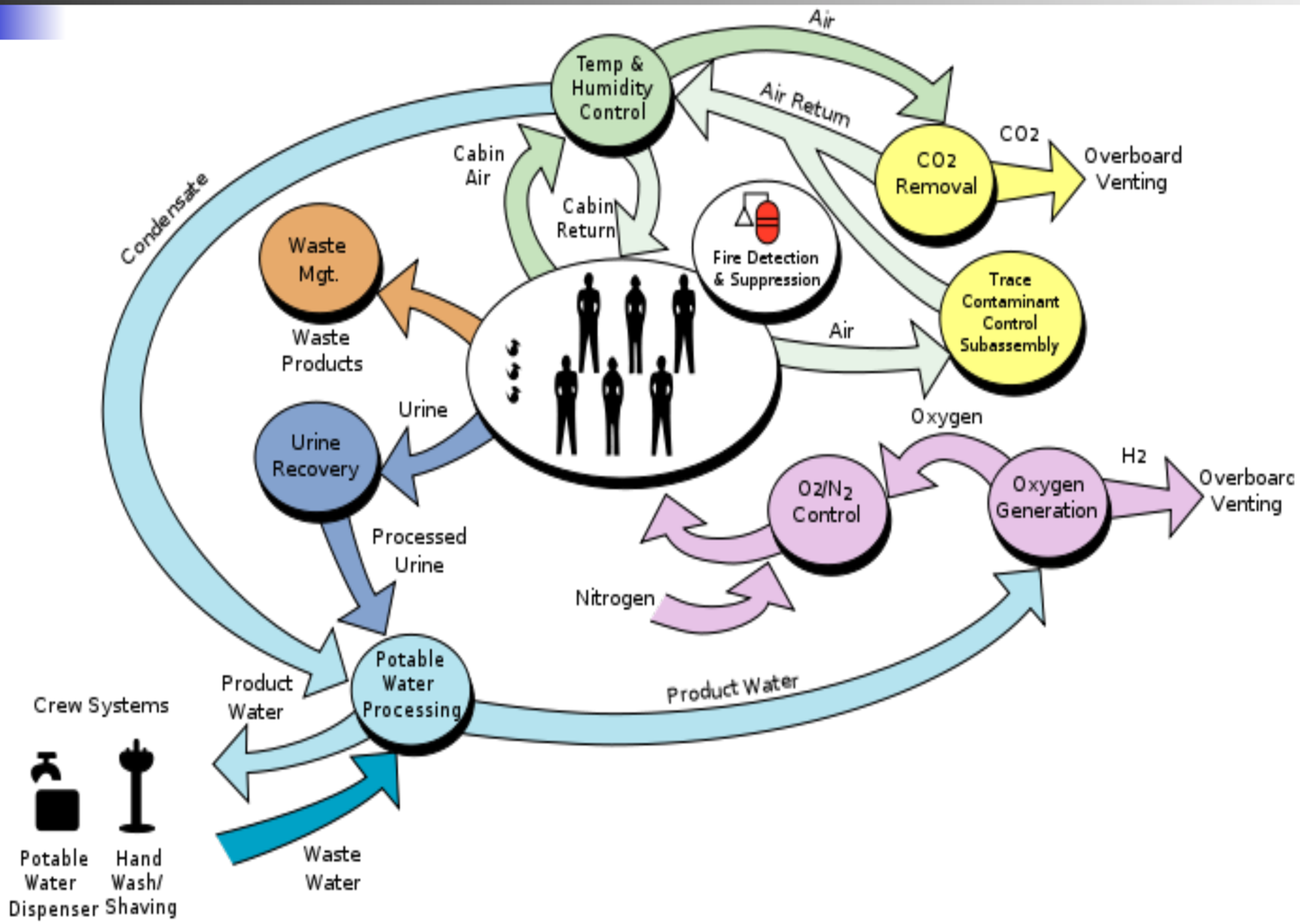
EVA
(0.2-0.5 kW, 1-4 kWh)

Lunar Pressurized Rover
3-10 kW, 25-100kWh

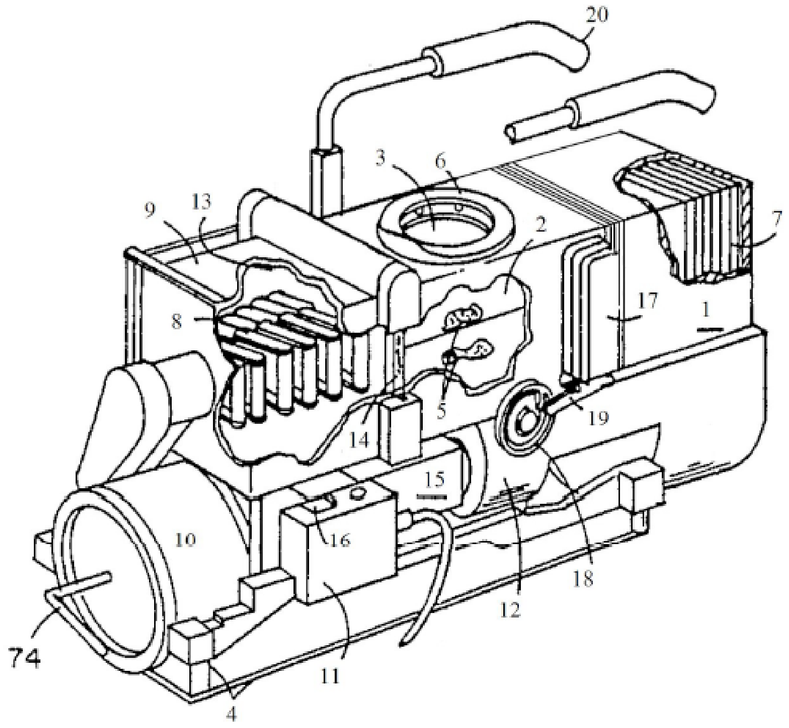


Lunar Habitat
(15-30 kW, 5MWH)

Waste Management

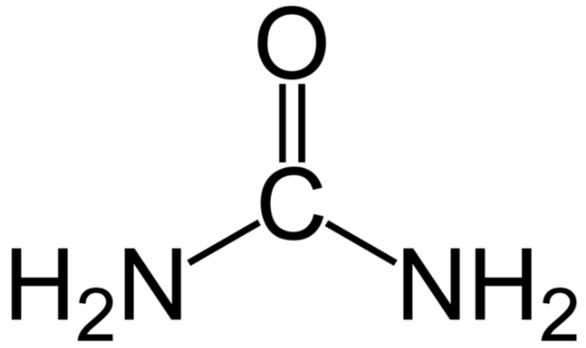


Waste Management

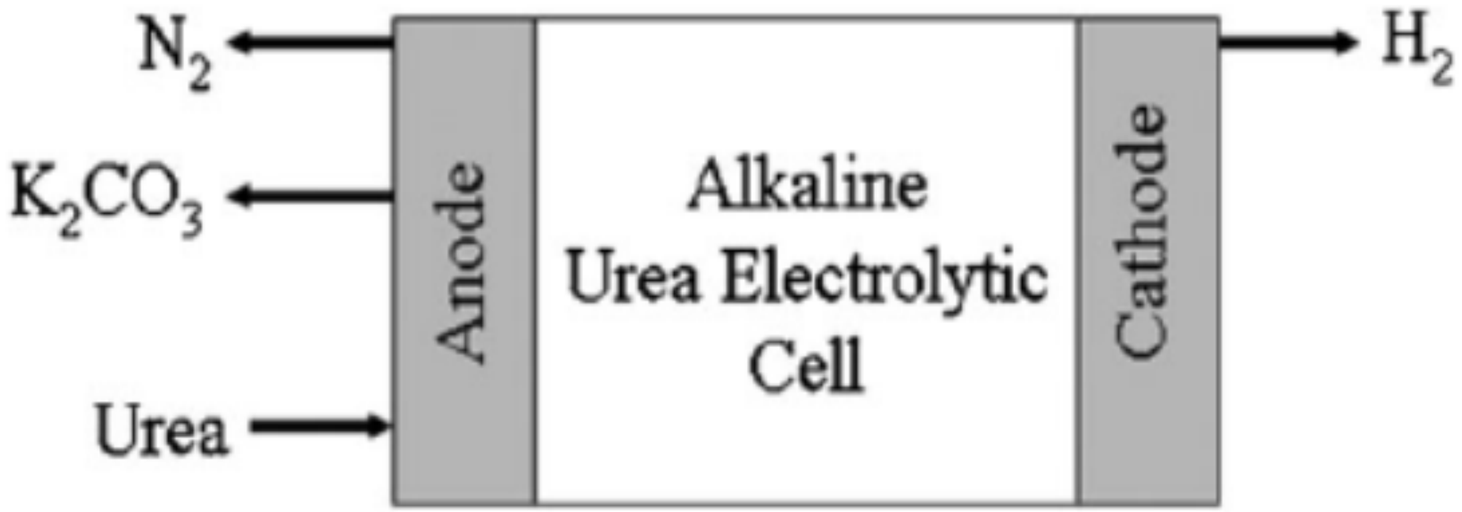


Urea properties

Molecular formula	CH_4N_2O
Molar mass	**60.06 g mol^{-1}**
Appearance	**White solid**
Density	**1.32 g/cm^3**
Melting point	**133 – 135 ^{o}C**
Solubility in water	**51.8 g/100ml (20 ^{o}C)**
	71.7 g/100ml (60 ^{o}C)
	95.0 g/100ml (120 ^{o}C)



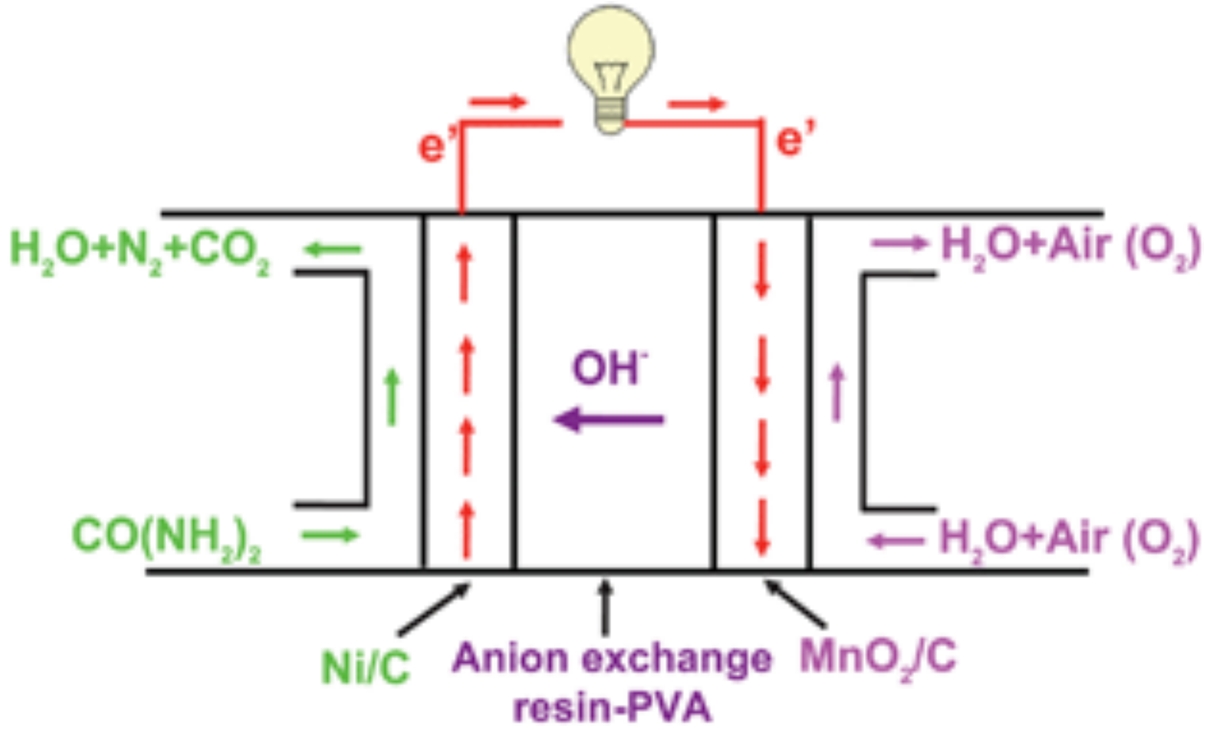
Urea as a Hydrogen Carrier



0.33 M Urea, inexpensive Ni catalyst, electrochemical oxidation.

Bryan K. Boggs, Rebecca L. King, Gerardine G. Botte* ,"Urea electrolysis: direct hydrogen production from urine", in *Chem. Commun.*, 2009, 4859-4861. (Dept. of Chemical and Biomolecular Engineering, Ohio University, Athens OH)[2]

Direct Urea Fuel Cell



Rong Lan, Shanwen Tao*, and John T. S. Irvine, "A direct urea fuel cell – power from fertiliser and waste", in *Energy. Environ. Sci.* 2010, **3**, 438-441. (Herriot Watt University, Edinburgh. University of St. Andrews, Fife, UK).[3]

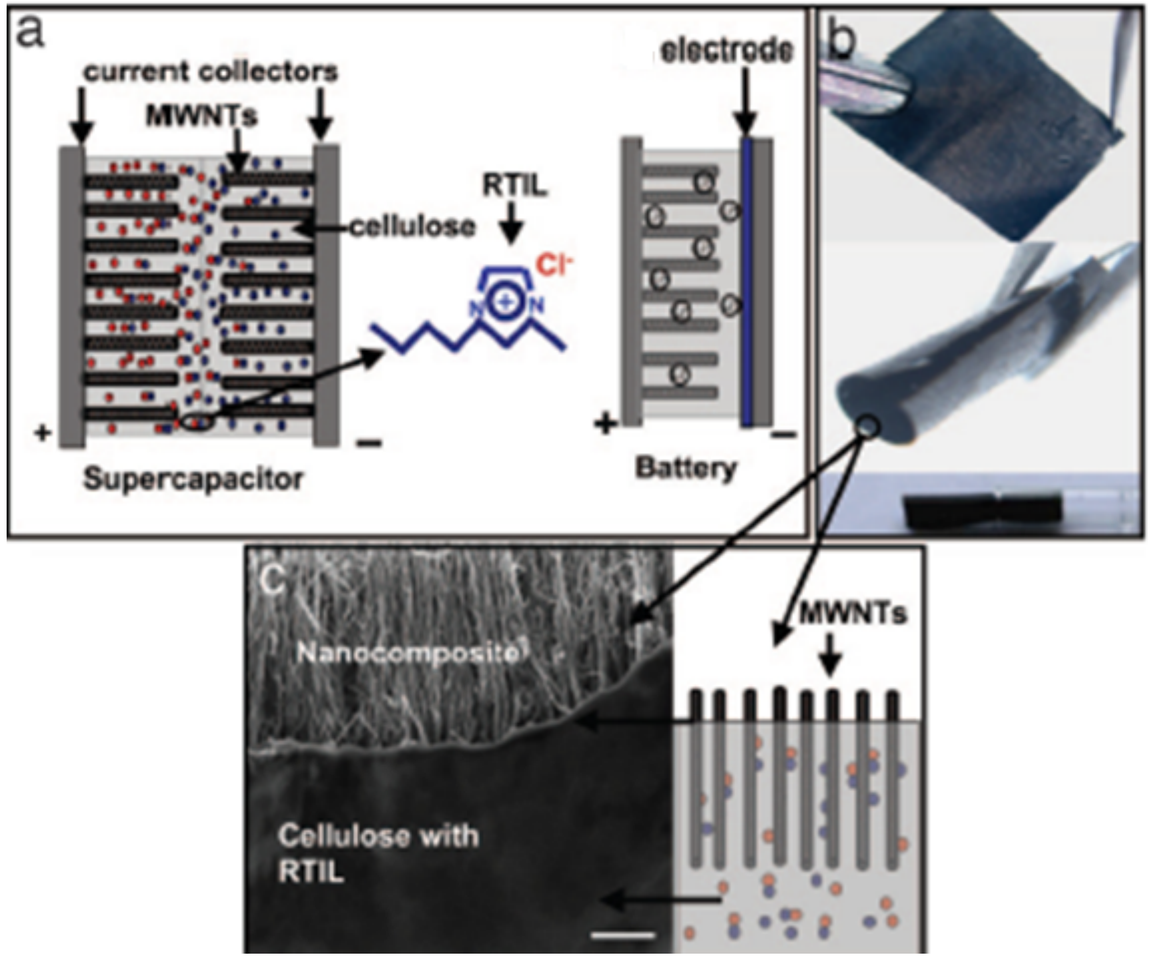
Direct Urea Fuel Cell

$$O_2 + 2H_2O + 4e' \rightarrow 4OH^-(\text{cathode reaction})\ E^0 = +0.40V \quad (1)$$

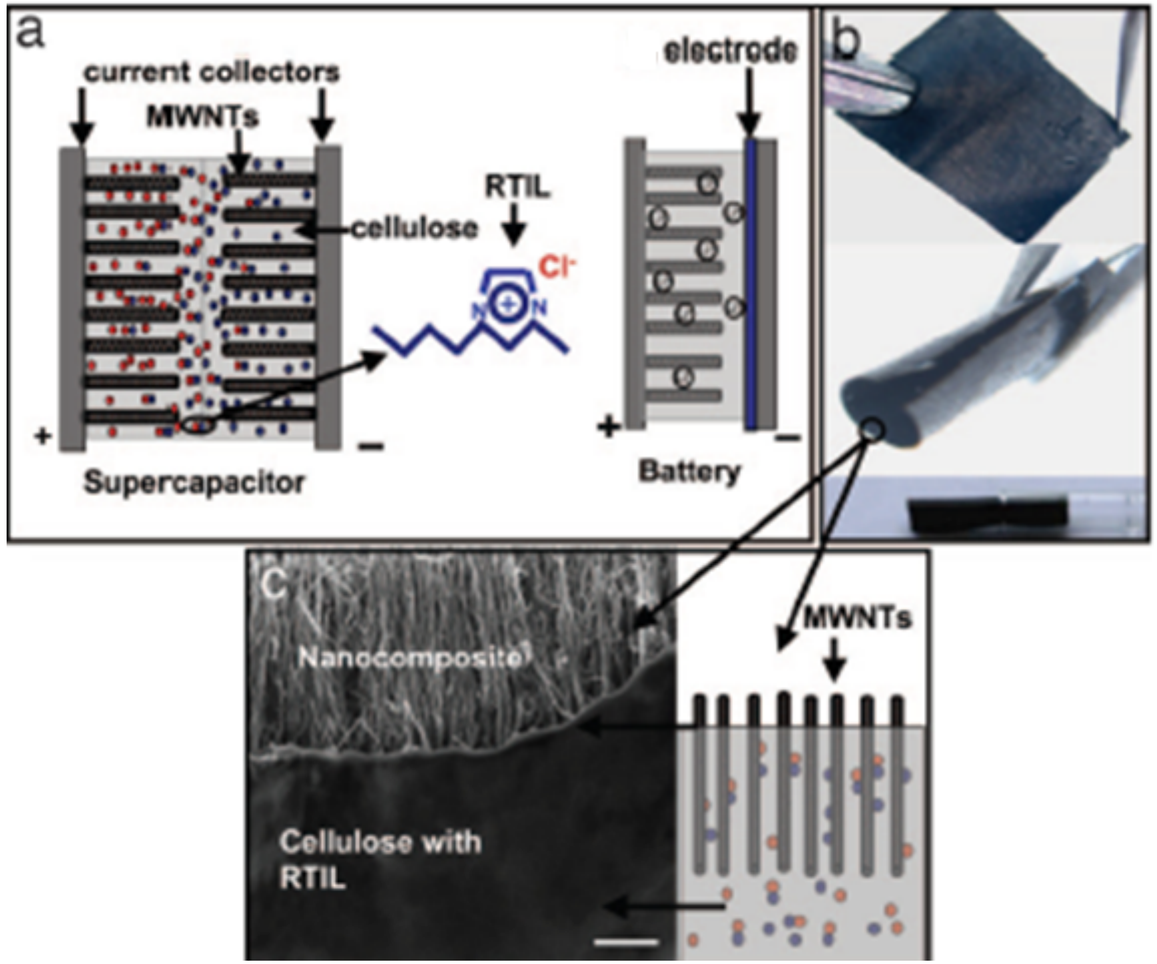
$$CO(NH_2)_2 + 6OH^- \rightarrow N_2 + CO_2 + 5H_2O + 6e'(\text{anode reaction}) \quad (2)$$
$$E^0 = -0.746V$$

$$2CO(NH_2)_2 + 3O_2 \rightarrow 2N_2 + 2CO_2 + 4H_2O(\text{overall reaction}) \quad (3)$$
$$E^0 = +1.146V$$

Hybrid FFC


a
current collectors
MWNTs
RTIL
cellulose
Cl-
+
–
Supercapacitor
electrode
+
–
Battery
b
c
Nanocomposite
Cellulose with
RTIL
MWNTs

Hybrid FFC


a
current collectors
MWNTs
RTIL
cellulose
Cl-
+
–
Supercapacitor
electrode
+
–
Battery
b
c
Nanocomposite
MWNTs
Cellulose with
RTIL

Project goal

- The aim of the project is to develop an innovative hybrid fuel cell technology dedicated to long distance manned outer space missions. The hybrid fuel cell technology shall integrate Membrane Electrode Assemblies (MEA) for electrochemical decomposition of urea and charge accumulation layers.
- The scientific research have been conceived as fundamental and industrial research activities in order to identify the most suitable nanostructured materials and architectures for the development of high efficiency and compact electrochemical hybrid cells for future power supply and energy storage systems dedicated to spacecrafts for long distance manned missions.

Project objectives

- Identification of a research niche in the area of energy supply and storage systems dedicated for spacecrafts using de decomposition of urea;
- The development of a partnership between a spin off company and a university research group in developing a interdisciplinary high performance research activity to be applied in innovative products;
- The enhancement of cooperation between a Romanian company and the International Space Station using services offered by different intermediate companies;
- Identification of possibilities to participate in ESA programs for the promotion of original Romanian products.

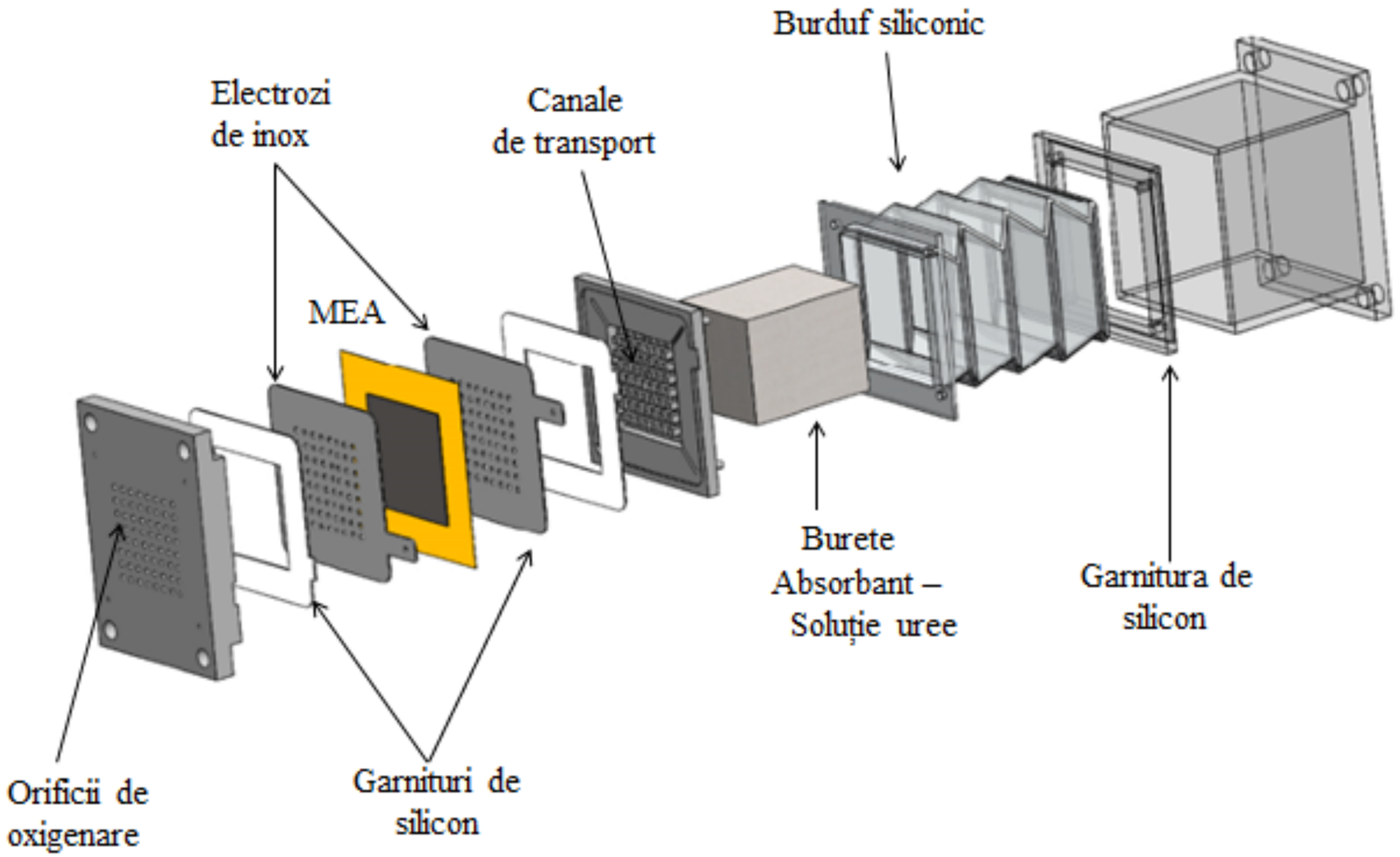
Expected outcomes

- The expected outcome of the research project is the accumulation of knowledge beyond the state of the art by integrating electric charge accumulation layers in the fuel cell MEAs and the development of hybrid technologies;
- The envisaged accumulation of knowledge based on the activities proposed by the current project shall offer a solid background for conceiving high efficiency and high density power supply systems, integrated into the waste neutralization and recycling loops dedicated to spacecrafts;
- The expected research results will allow accumulating the knowledge for developing innovative products that might be used as energy supply and storage systems fed by urine during the manned long distance missions;
- The results of the research projects might have also a large impact in the eco innovative solutions for waste treatment in urban agglomerations for other specific conditions that required urine neutralization;
- Large scale industrial applications might be developed for distributed energy production using industrial urea as an energy carrier;

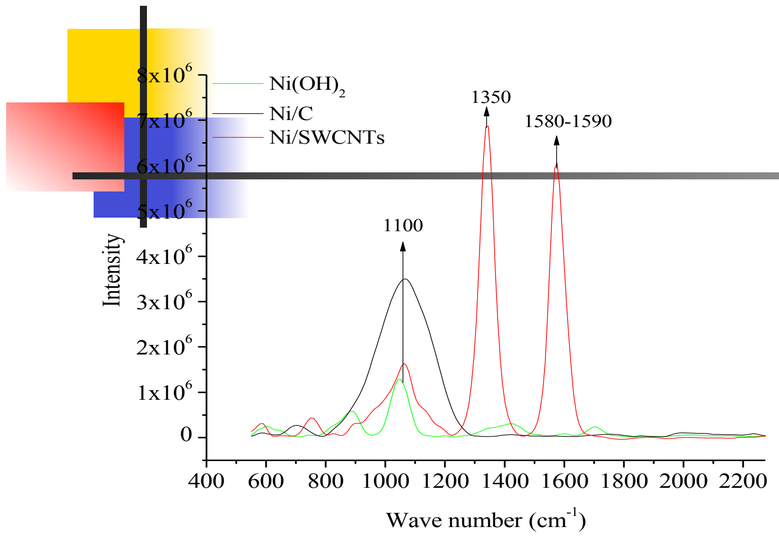
Current status

UFC Module	Components/Materials/ Parameters
Anode	The anodic electrolite chamber, Acrylonitrile butadiene styrene (ABS), S= 6.5×6.5cm^2, V electrolite=8.74ml
	Anodic electrode, Stainless steel, S= 16 cm^2
MEA Assembly	1. MEA 1 Ni/C(Anode) and MnO_2(Catode), Active surface=9cm^2
	1. MEA 2 Ni/SWCNTs(Anod)and MnO_2(Catod), Active surface=9cm^2
	1. MEA 3 $Ni(OH)_2$(Anod) and MnO_2(Catod), Active surface=9cm^2
Catode	Purging surface for humidified O_2, Acrylonitrile butadiene styrene (ABS),S=2.5×3.5cm^2
	Oxidant chamber (for the measurments it was used a solution of 20% $H2O_2$+5% H_3PO_4), Acrylonitrile butadiene styrene (ABS), S=6.5×6.5cm^2, V oxidant=8.74ml
	Catodic electrode, Stainless Steel, S=16 cm^2

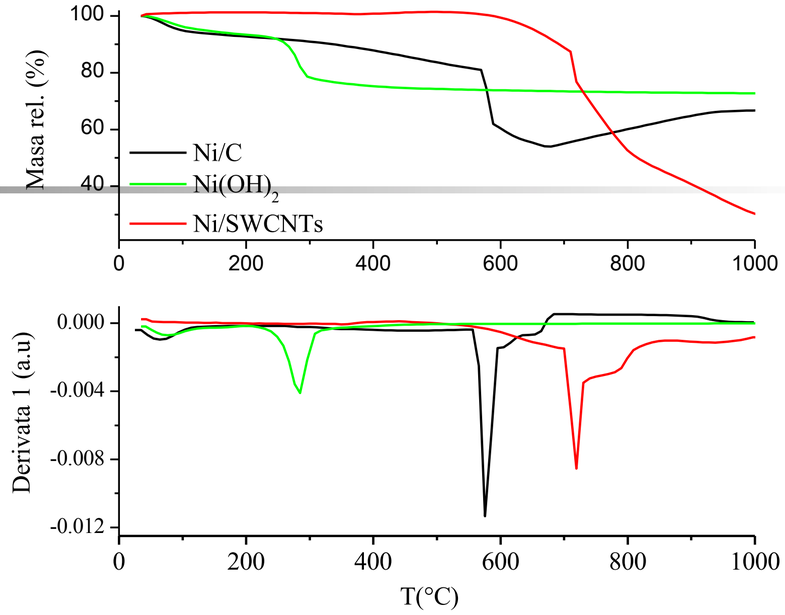
Current status



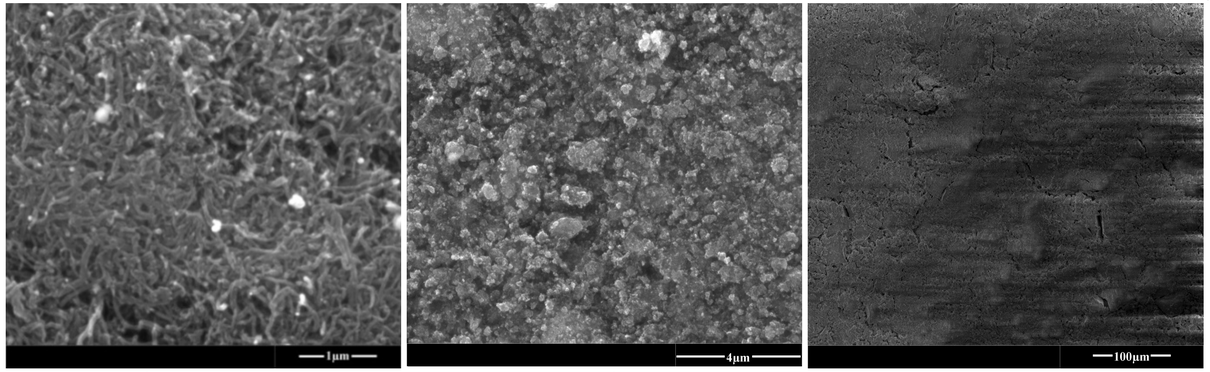
Lab Results



Raman Spectre for catalysts: Ni/C, Ni/SWNTs and $Ni(OH)_2$



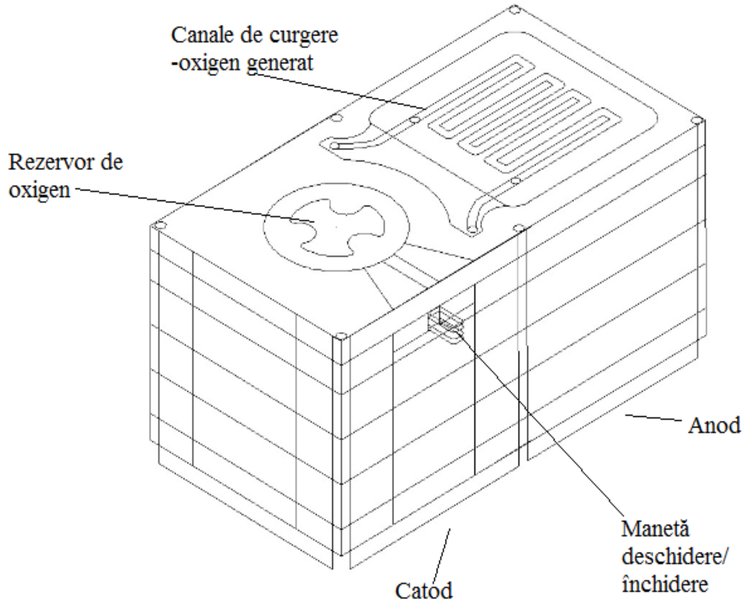
TGA diagrams for catalysts: Ni/C, Ni/SWNTs and $Ni(OH)_2$



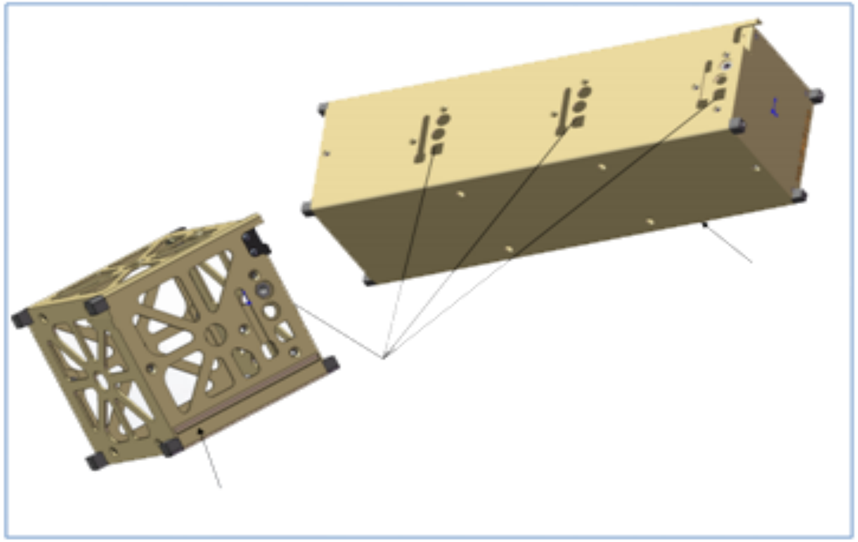
a. Ni/SWCNTs X50000 *b. Ni/C X20000* *c. $Ni(OH)_2$ X500*

SEM Image for catalysts : Ni/SWNTs(a), Ni/C(b) and Ni(OH)2(c) with magnifying factor of X50000, X20000 and X500

Payload preparation

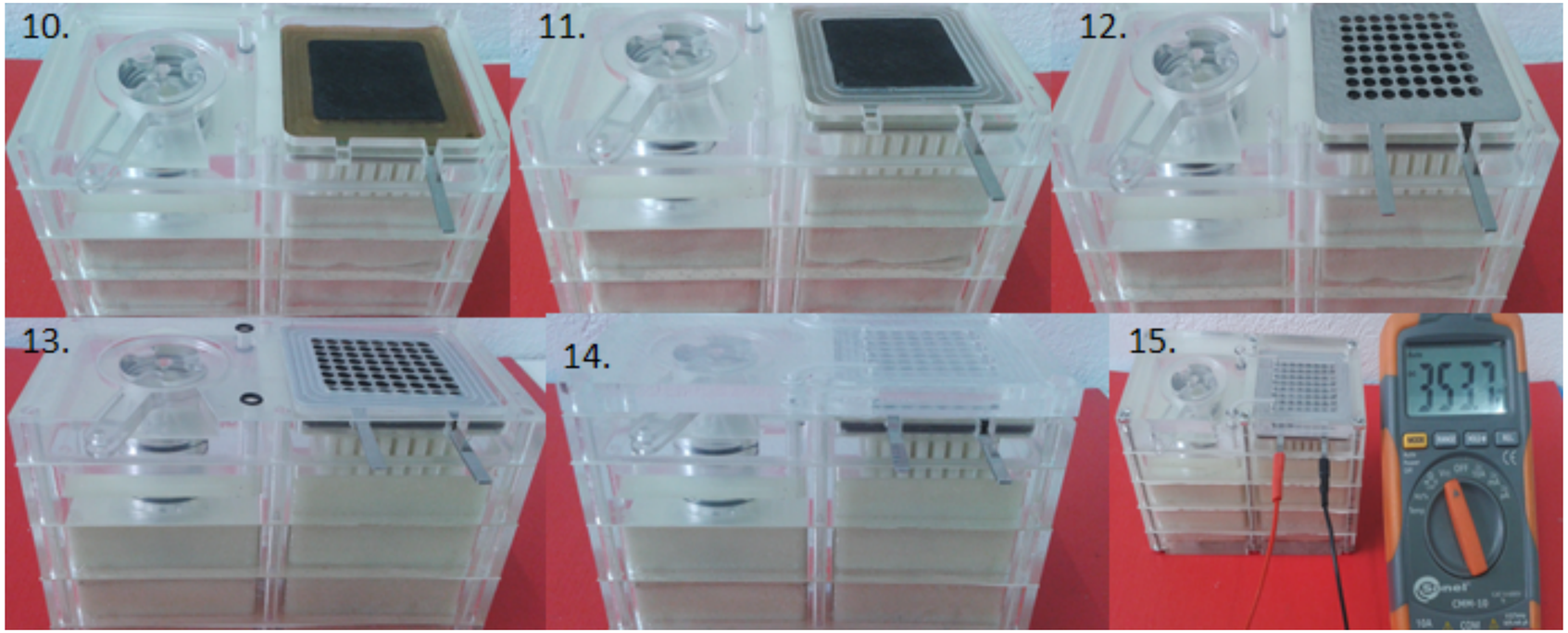


Fuel cell 3D architecture

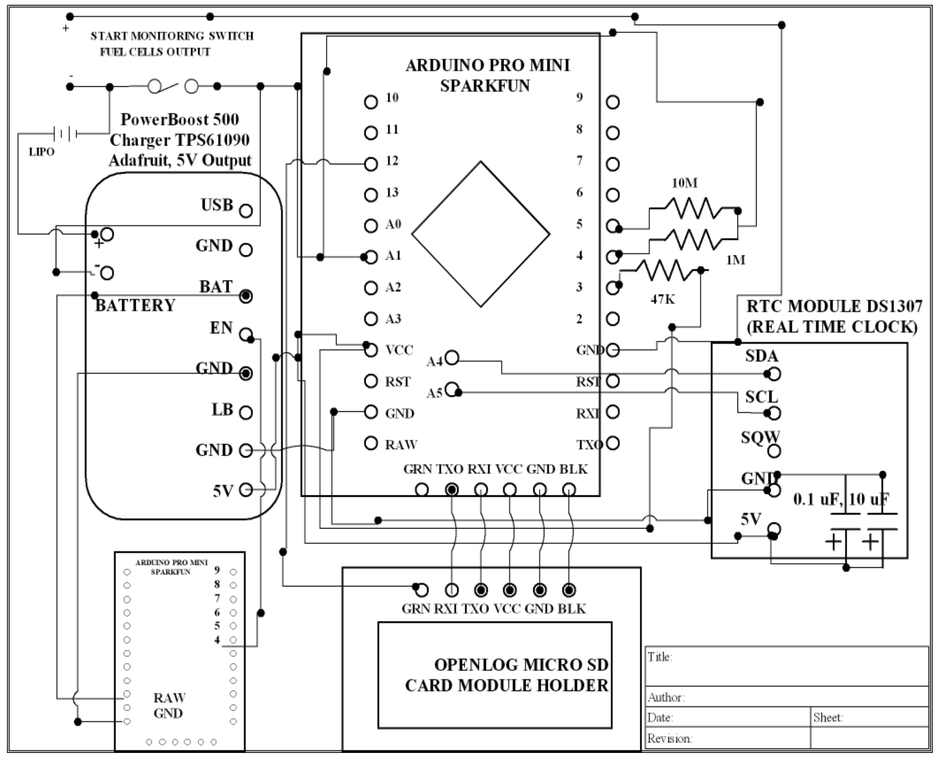


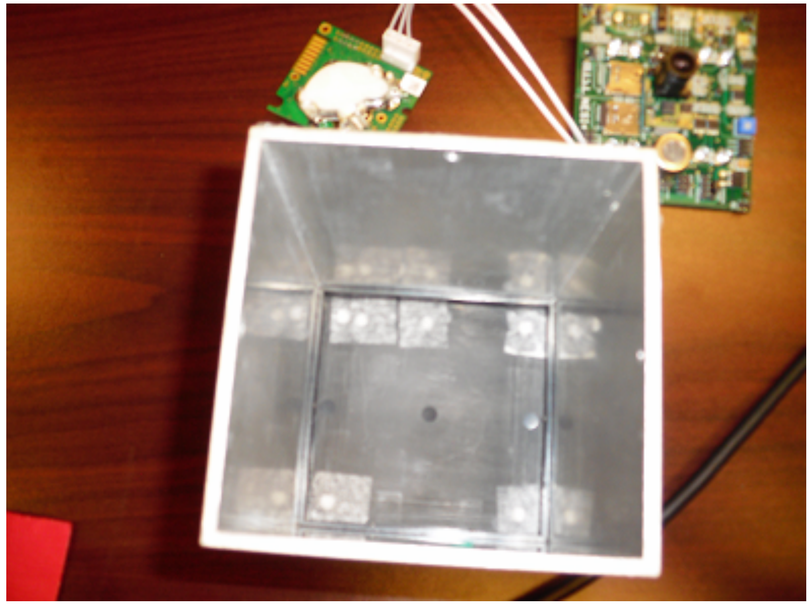
Nano-lab Module Architecture

Payload preparation



Payload preparation





Conclusions

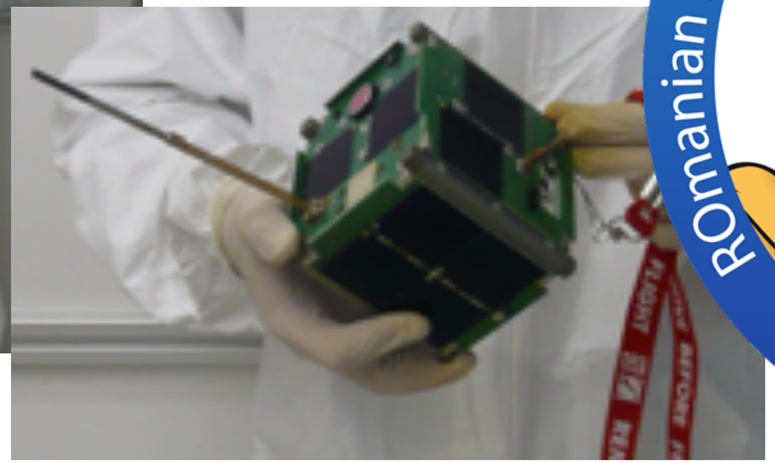
- The payload is prepared for starting the procedures for safety checks;
- The Romanian Space Agency accepted to extend the project for 1 year in order to be organized the transport to the ISS and development of the micro-gravity tests;
- The experiments that have been carried out up to now have facilitated the accumulation of a large volume of data and experience;
- It has been also a very successful collaboration between a University research team and an SME.

Thank you for your attention!

and please, send your comments at:
dorin52@yahoo.com

Romanian nanoSatellite Technology - Competence Centre ROST-CC

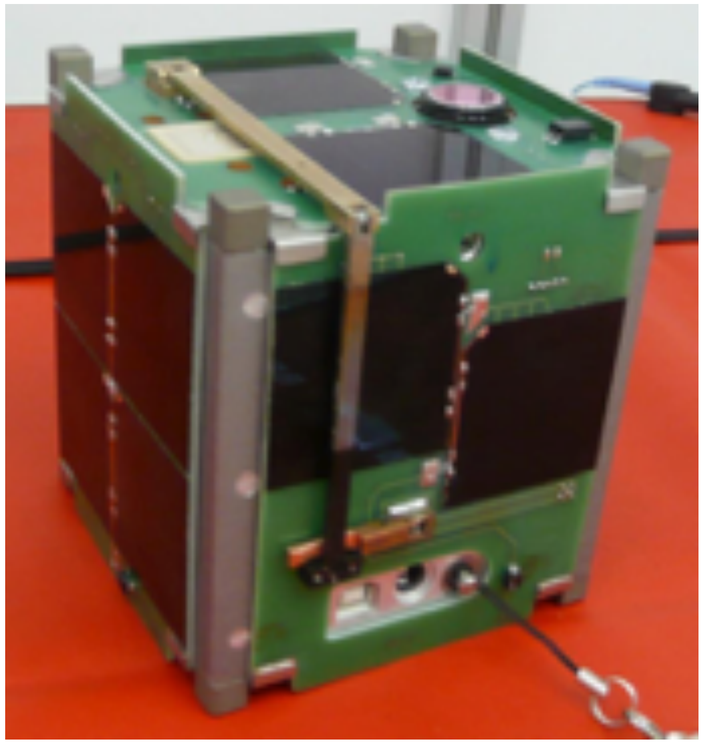
Dumitru-Dorin Prunariu, PhD
Member of the Board, Romanian Space Agency



Manager: dr.fiz. Mugurel BALAN
Institute of Space Science, ROMANIA
mugurelbalan@spacescience.ro
Tel:+40 724 379702

Who are we?

- Our team has developed CubeSat GOLIAT - First Romanian Satellite
- The GOLIAT satellite has been **developed, integrated and tested** according with **ESA standards and VEGA ICD**
- The “Paper Satellite” has been approved by ESA experts



Who are we?

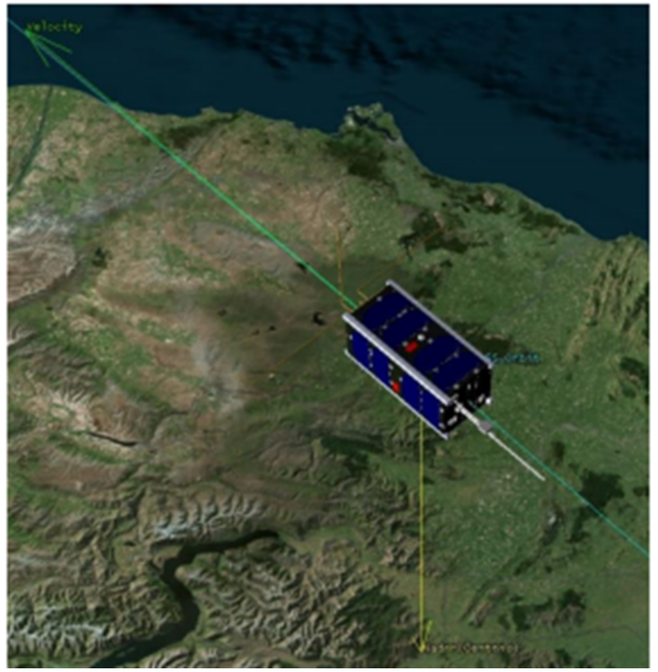
- The nanosatellites research group is part of the Gravity, Microgravity and Nanosatellites Laboratory
- It was established during the development of GOLIAT – first Romanian CubeSat

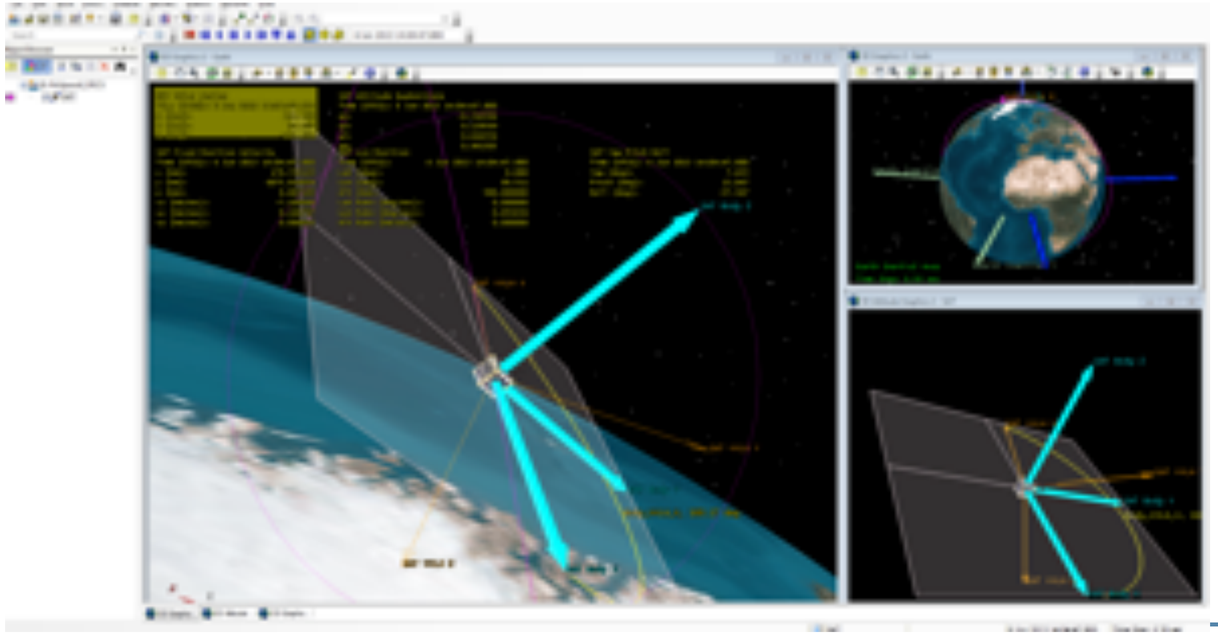
- The group consists of 8 scientific researchers mainly covering: physicists, electrical engineers, aerospace engineers, software engineers.

Mission Design

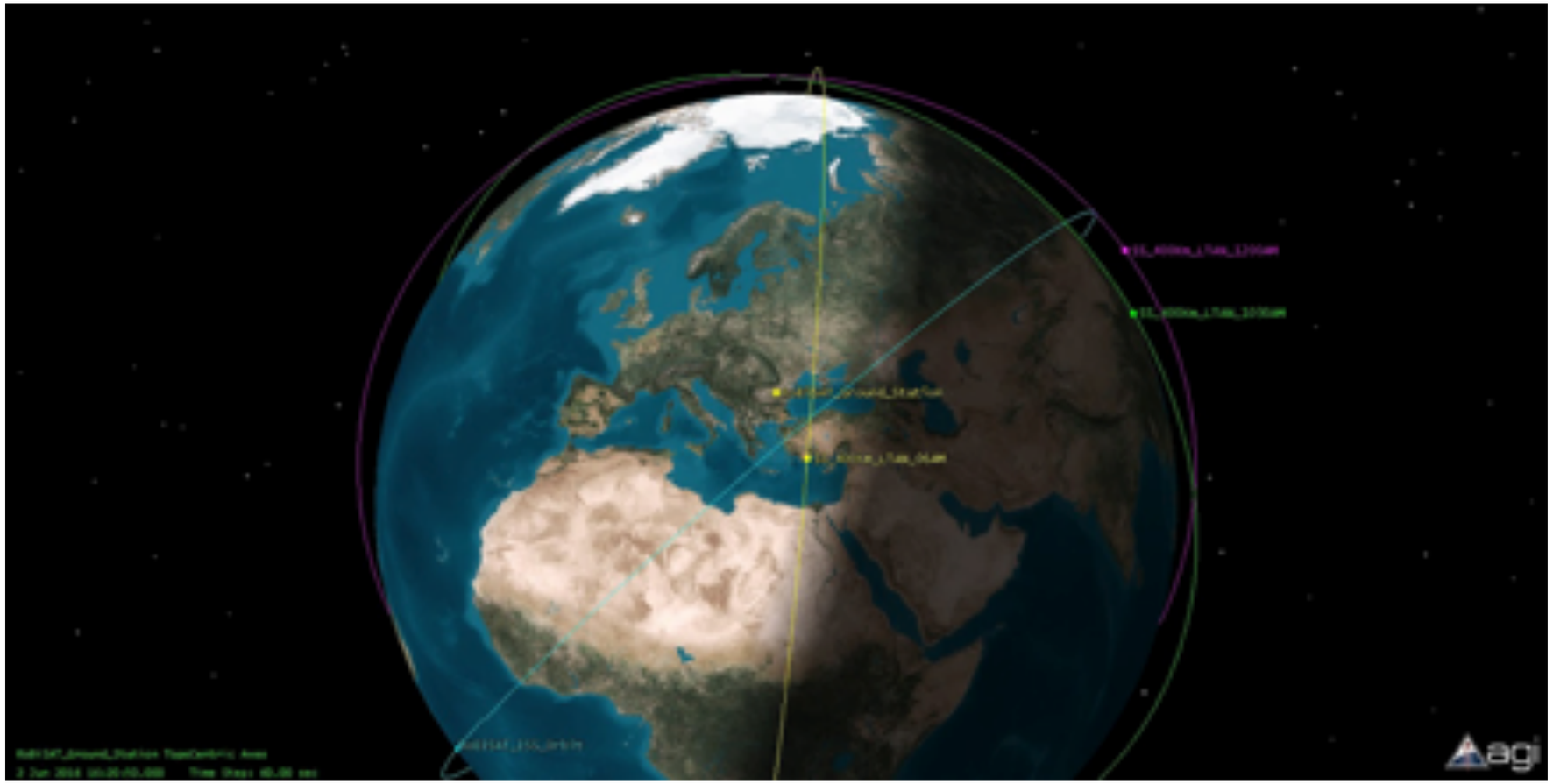
AGI STK SW Platform

- Mission design
- Mission analysis
- Mission Requirements
- Space Environment Effects

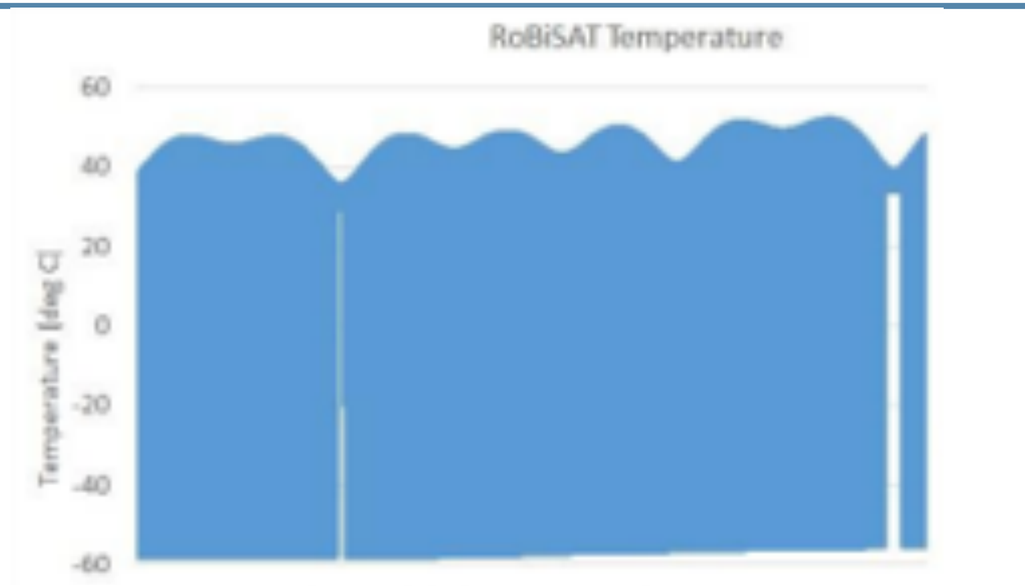


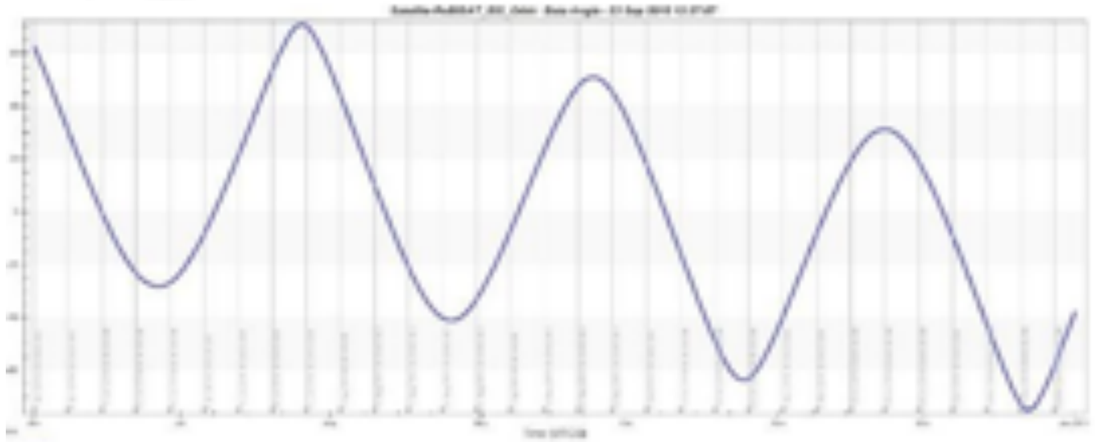


Orbit Selection

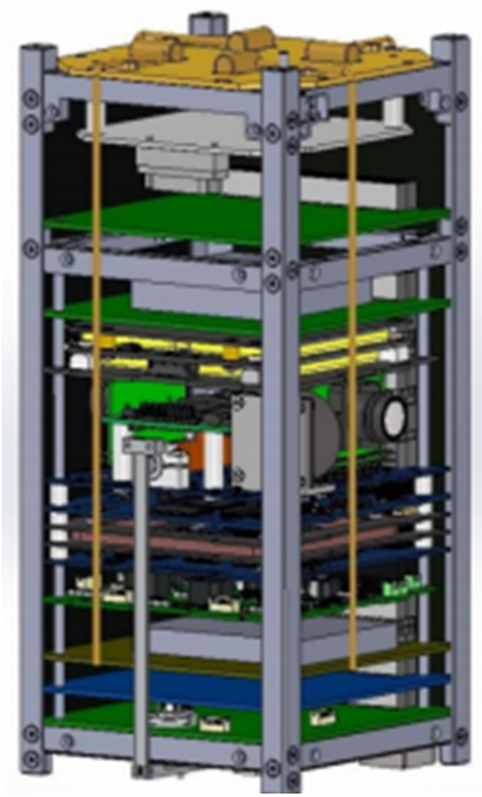


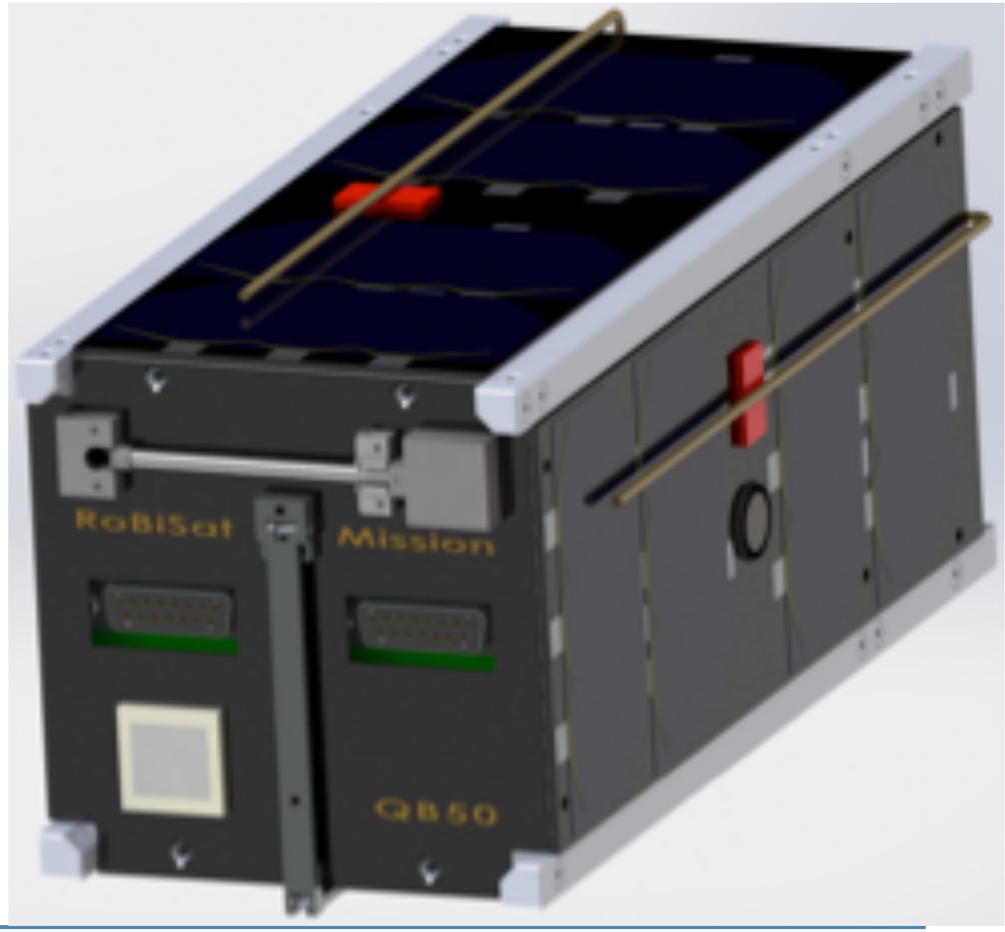
Initial assessment



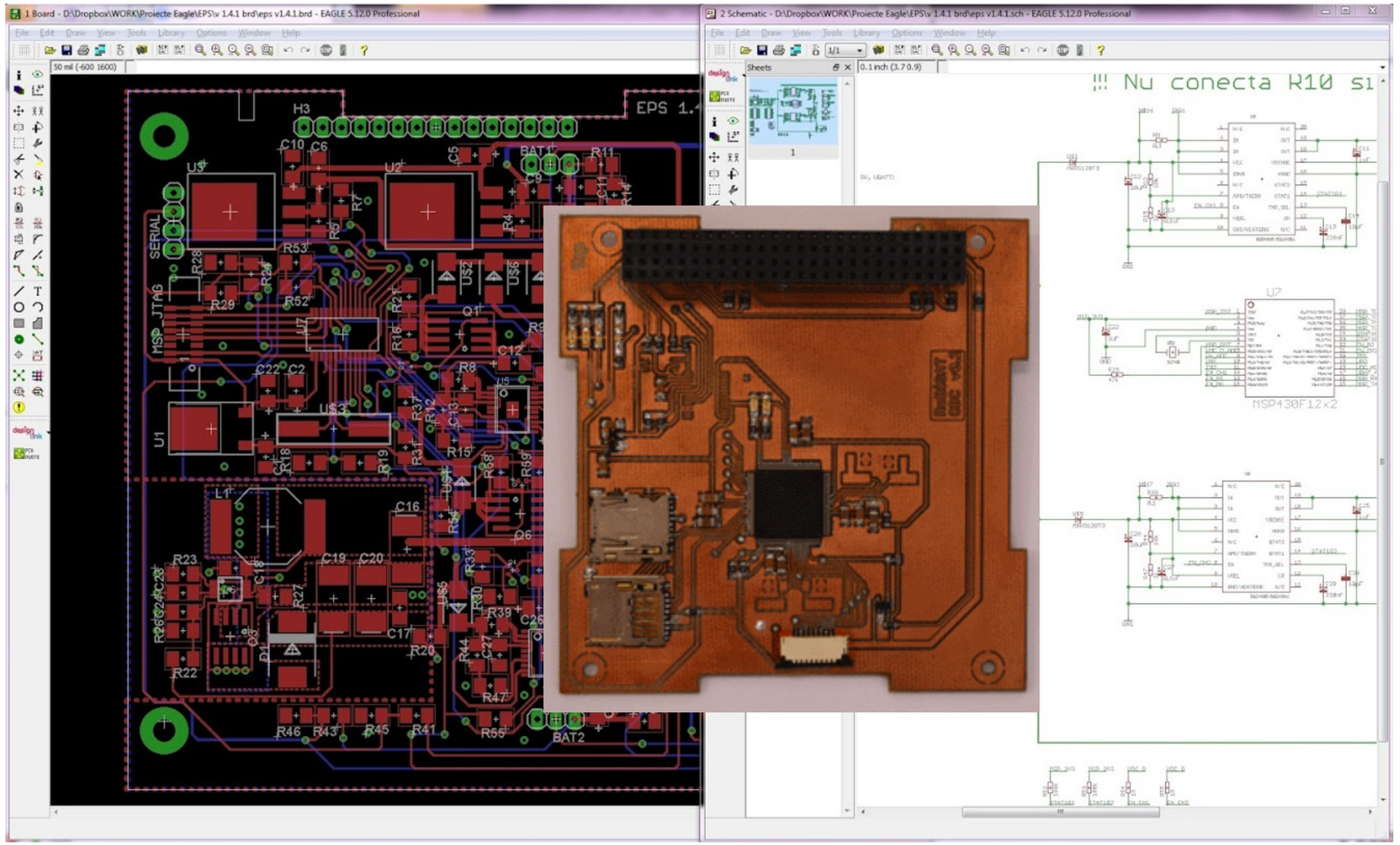


CAD Design





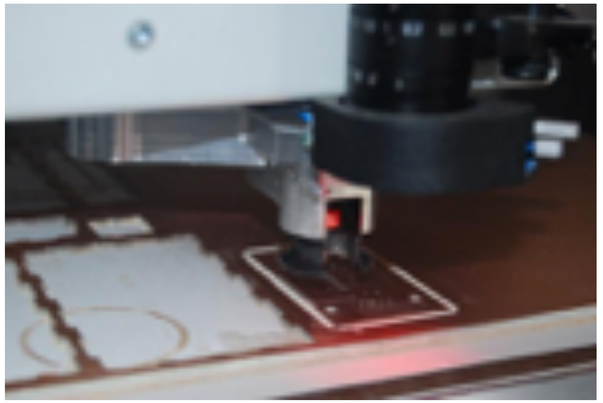
Printed Circuit Board Design



Breadboarding

Electronic test bench:

- Oscilloscope & logic analyzer Agilent 350 MHz, dual channel.
- Precision multimeter Tektronix DMM 4040, 6.5 digits
- 6 variable power supply units 0-30 V, 0-3 A
- Portable multimeters

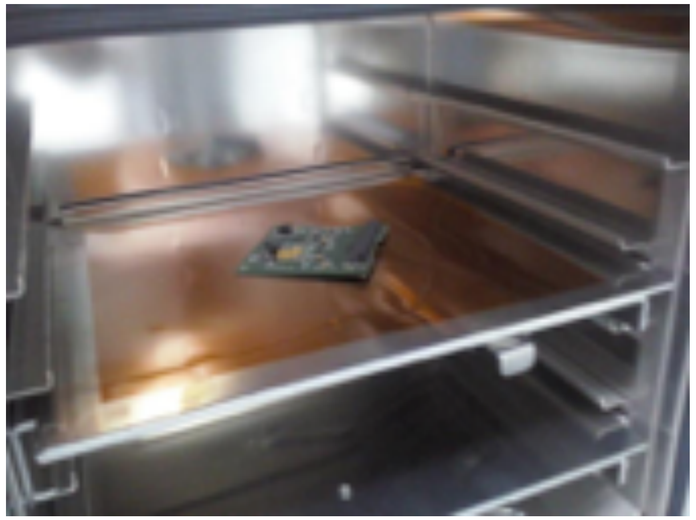


LPKF S63 – rapid prototyping for electronic boards manufacturing including RF boards

PCB integration bench equipped with soldering station and microscope for SMD integration, stencil mate, reflow oven

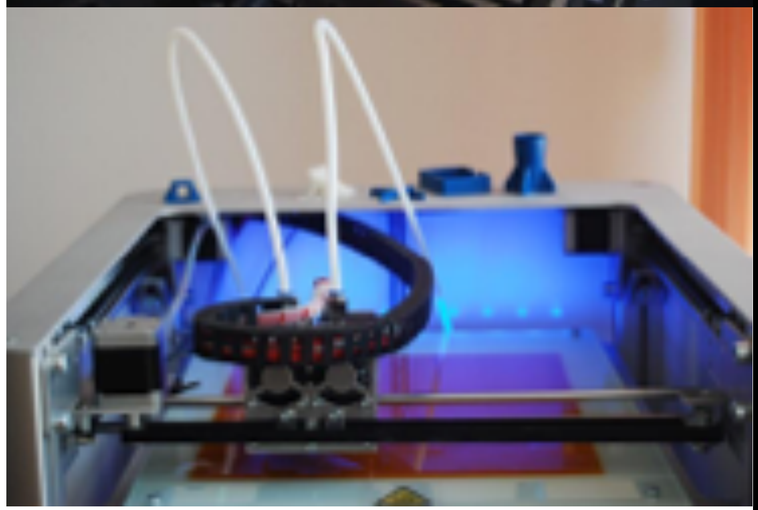
Thermal Backing out

- Thermal baking-out equipment
  - 1.5 mBar vacuum
  - Up to 200 C temperature control
- Conformal coating deposition installation (planned)



3D Print and Manufacturing

- Mechanical assembly and manufacturing facility equipped with:
  - CNC precision milling machine
  - 3D Printer for rapid prototyping



Assembly Integration & Testing (AIT).

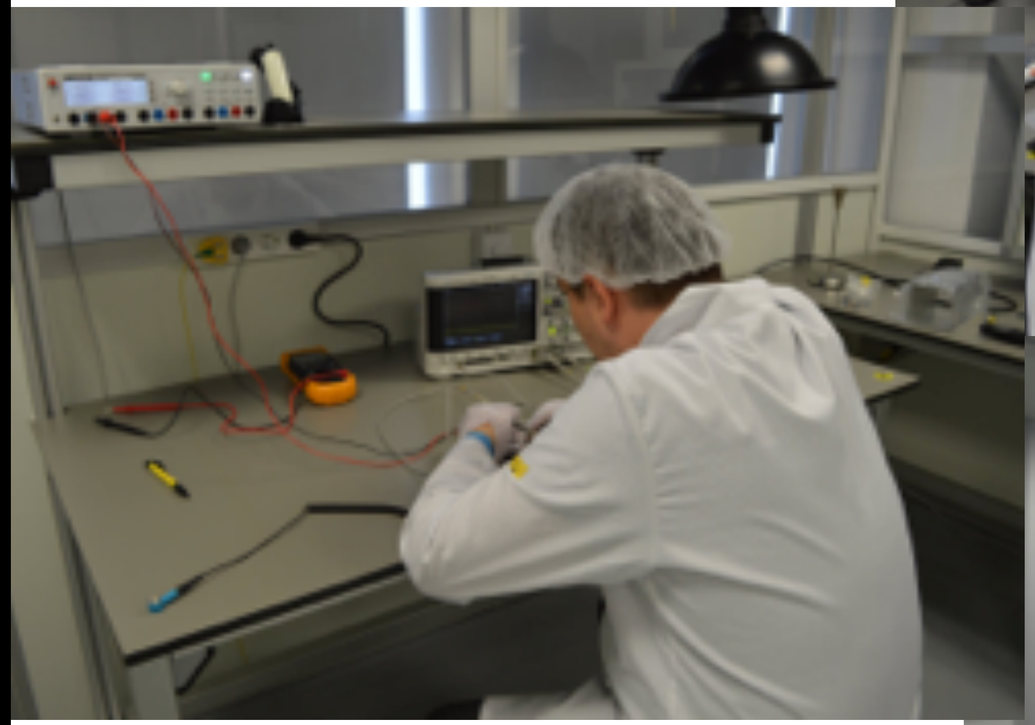
Clean Room facility

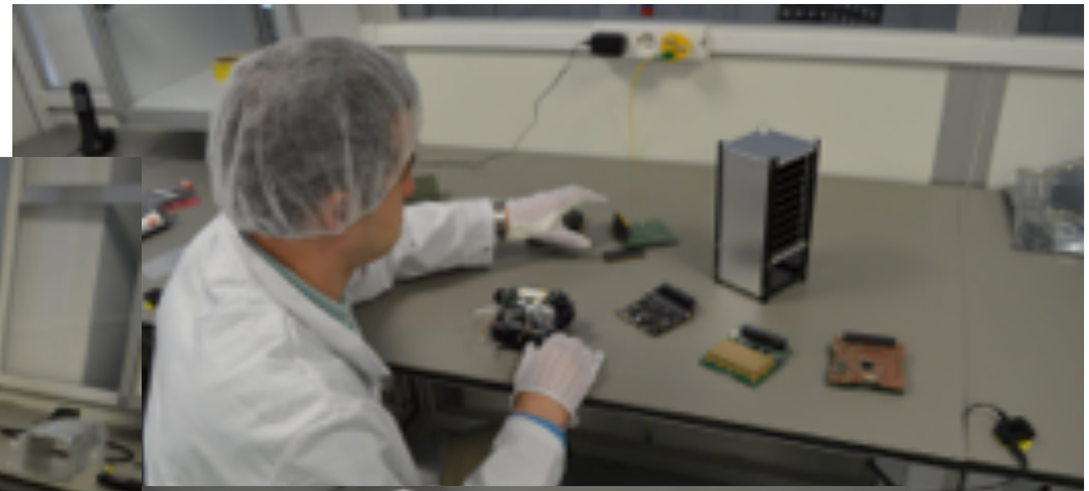
- ISO 8 standard
- 16 mp area
- Designed according to the ECSS–Q–ST–70–01C standard
- Continuous monitoring system including:
  - Temperature sensor
  - Humidity sensor
  - Differential pressure sensor
  - Particle counters
- ESD furniture & equipments
- Local exhaust system for soldering processes.

INSTITUTE OF SPACE SCIENCE

Assembly Integration & Testing (AIT).

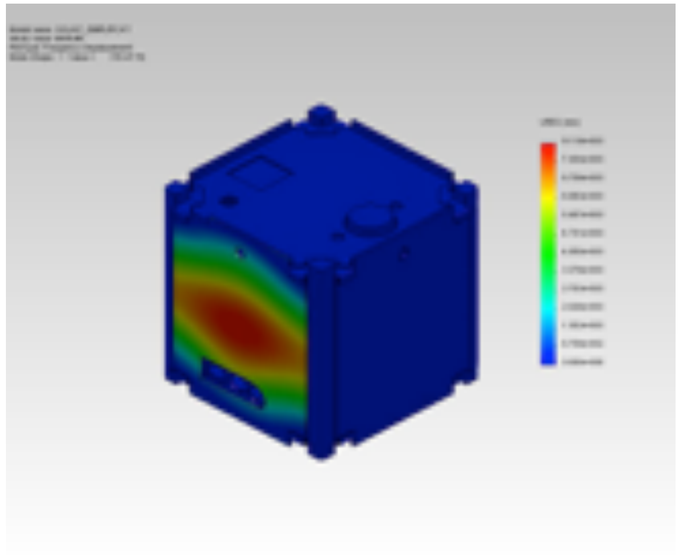
Assembly Integration & Testing (AIT).



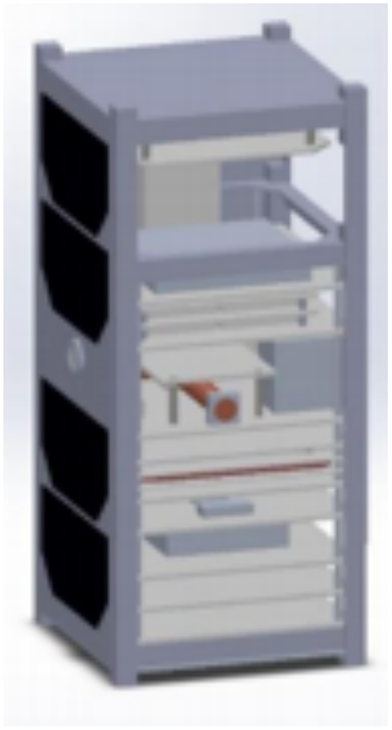


Finite Element Analysis

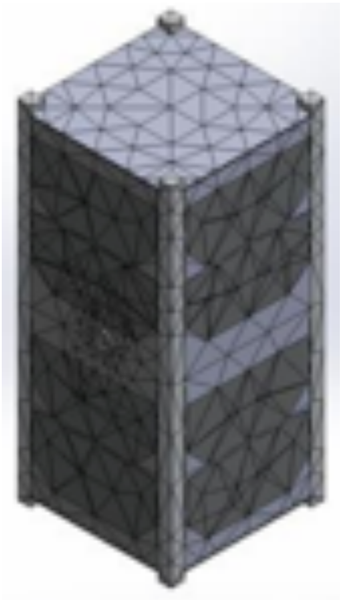
- Static Load
- Sin Vibration
- Random Vibration
- Thermal Analysis
- Shock SRS



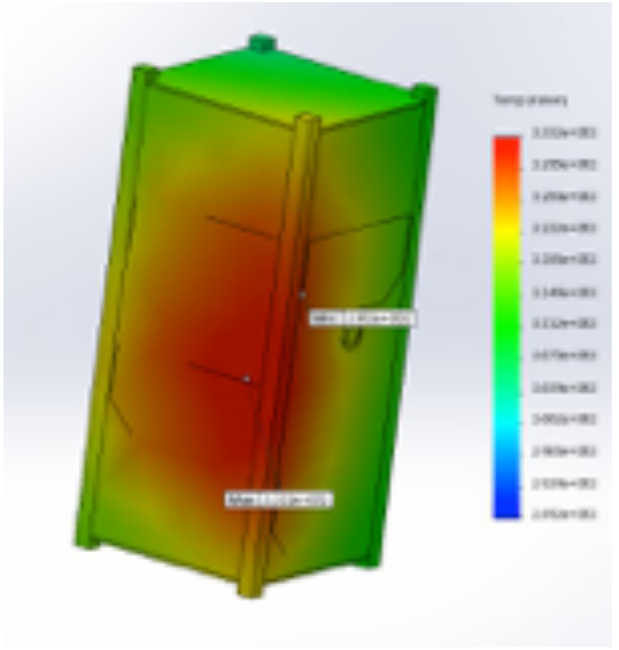
Finite Element Analysis



Simplified CAD Model



FEA Mesh

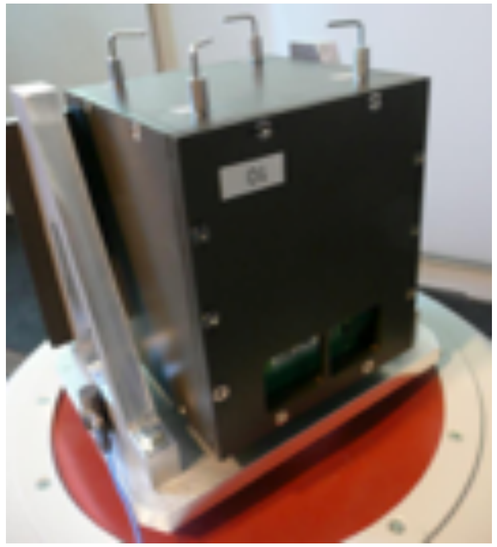


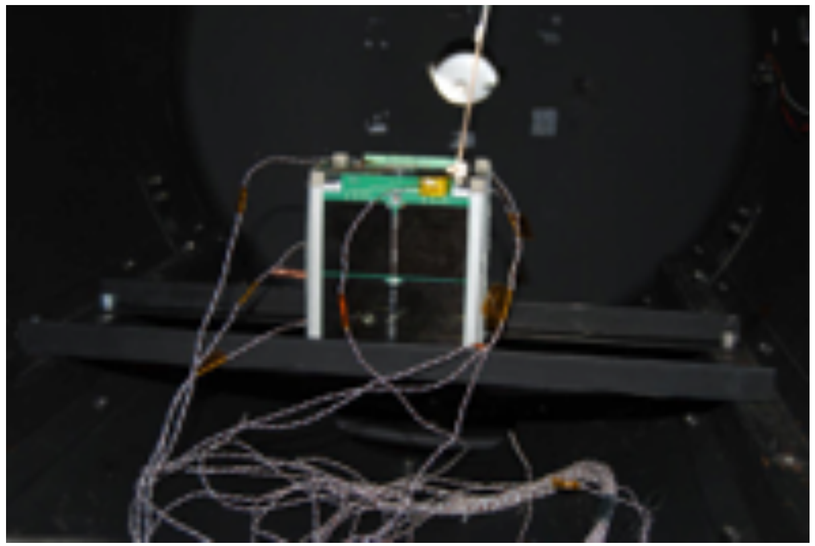
Thermal Analysis

Testing

Work experience with ESTEC test team and local partners.

- Shaker – mechanical tests
- Thermal Vacuum Test



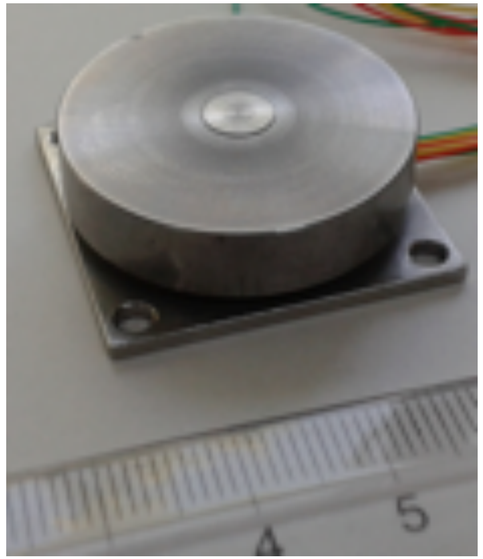


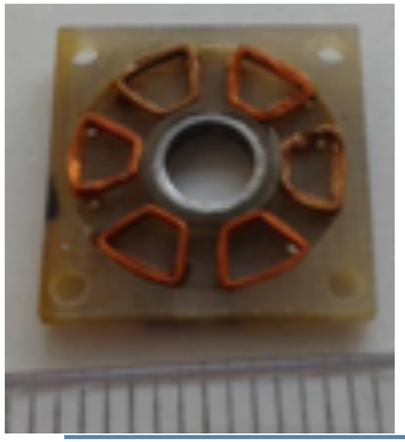
Mission Operation and ground infrastructure

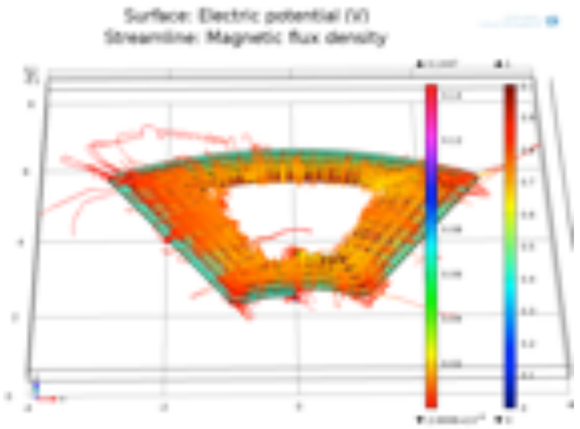
- ISS's HAM ground Station
  - UHF Up-link/Down-Link
    - ICOM 910H
    - 2 x 3.5 m Yagi Antennas – Az / El
  - S band
    - MHX 2400
    - 3 m dish – Az/El

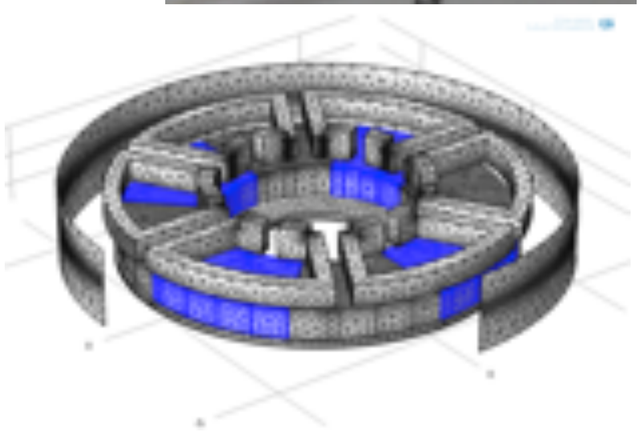
ROSA-ESA

- Industry collaboration project ISS-ICPE S.A SuNs Project
- Develop an experimental model of a micro-motor reaction wheel assembly designed for nanosatellites
- The project is funded through a national research grant.



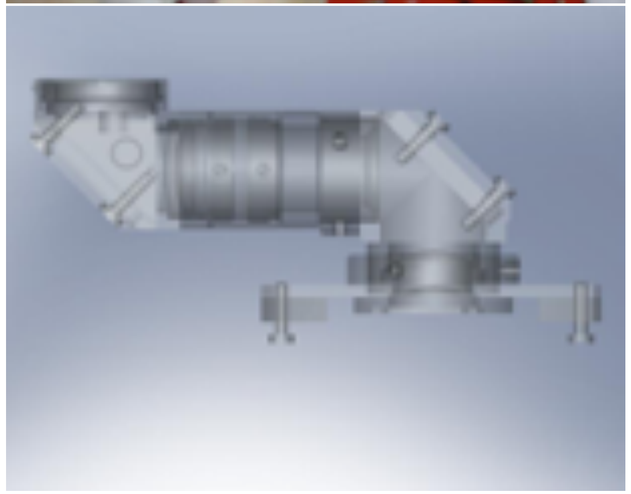






INDUSTRY PARTNERSHIP

- Custom Camera Lens Mount
  - Developed under collaboration with PROPTICA – a local company specialized in optical equipment's for defense and high accuracy applications.
  - Currently PROPTICA runs a ESA contract for manufacturing high precision optics.



ESA Contract

- 5 ESA contracts undergo
  - 3 Romanian Incentive Scheme
  - 2 EGEP Program

Directions of interest:

- Small platform development
- Spin-in technologies
- Payload development