1° Symposium On Space Educational Activities

1ST SYMPOSIUM SPACE EDUCATIONAL ACTIVITIES
PADOVA - 9/12 December 2015

Space Engineering and Small Satellites Educational Activities at University of Bologna

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Padua, 9 – 12 December 2015

Overview

- Department of Industrial Engineering at University of Bologna.
- History & Background: ALMASat-1 mission.
- The European Student Earth Orbiter (ESEO) project.
- Current activities: Missions & Space Technologies
  - Micropropulsion
  - GPS-Based Navigation
  - Ground Segment

DIN – Department of Industrial Engineering

DIN offers courses in:

- Aerospace Engineering
- Mechanical Engineering

In Forlì

Bachelor and Master's Degrees

Space-related exams:

- Fondamenti di Meccanica Orbitale
- Satelliti e Missioni Spaziali
- Spacecraft Orbital Dynamics and Control
- Spacecraft Attitude Dynamics and Control
- Spacecraft Subsystems and Space Mission Design

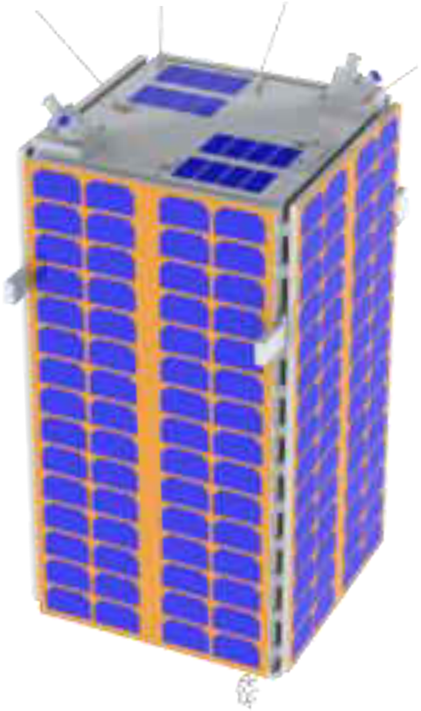
Microsatellite and Space Microsystems Lab
Radio Science and Planetary Exploration Lab

Microsatellite Platforms Heritage @ UNIBO

ALMASat-1

Launched in 2012
Vega Maiden Flight

ALMASat-EO



Launch TBD

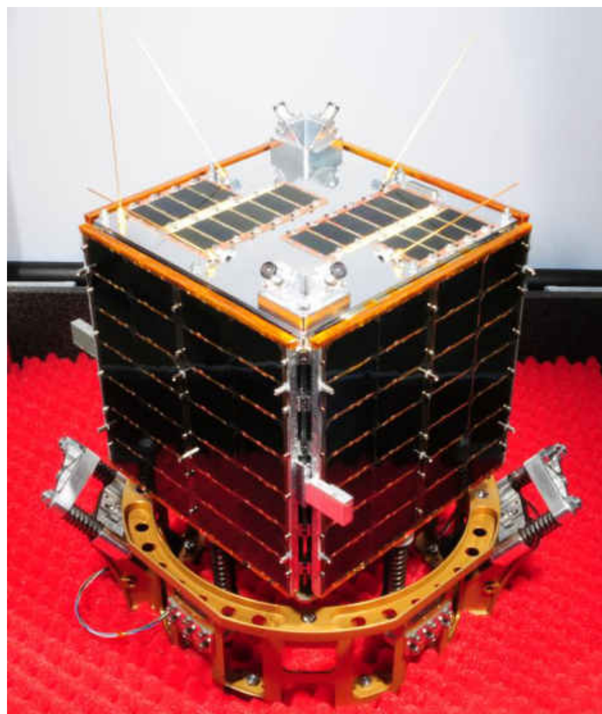
ESEO

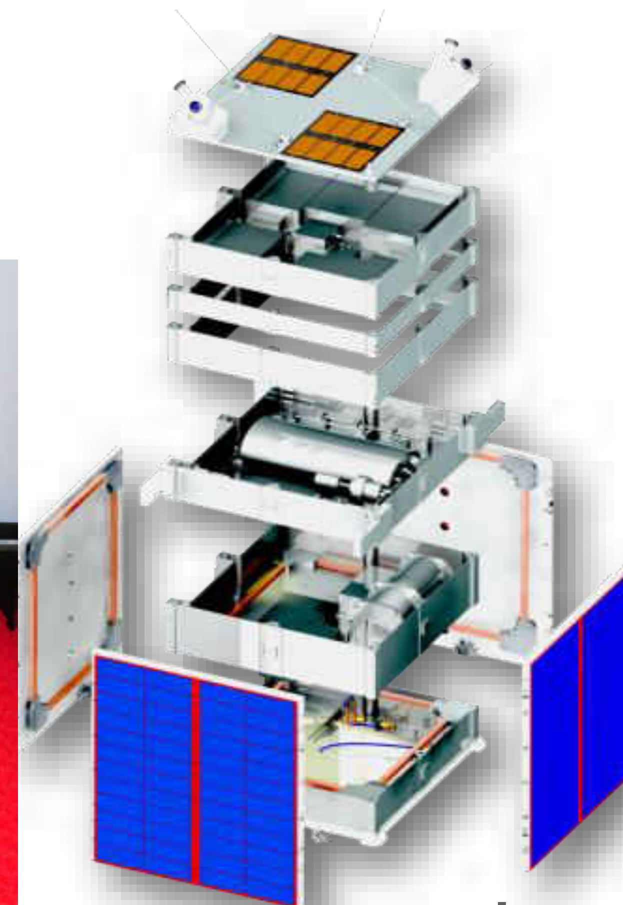
Launch 2017 (TBC)

Microsatellites and Space Microsystems

ALMA*Sat-1* (ALma MAter Satellite)

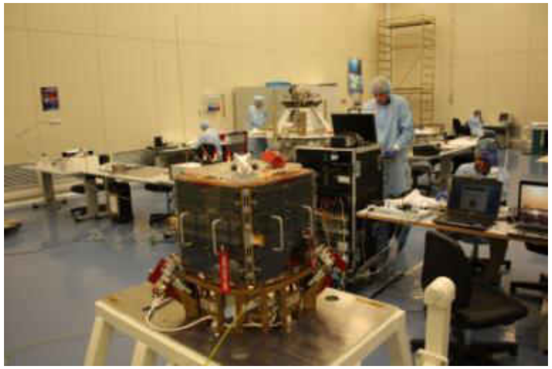
- Technology Demonstrator
- Micropropulsion Experiment
- Transmission Experiment at S-band (2.4 GHz)

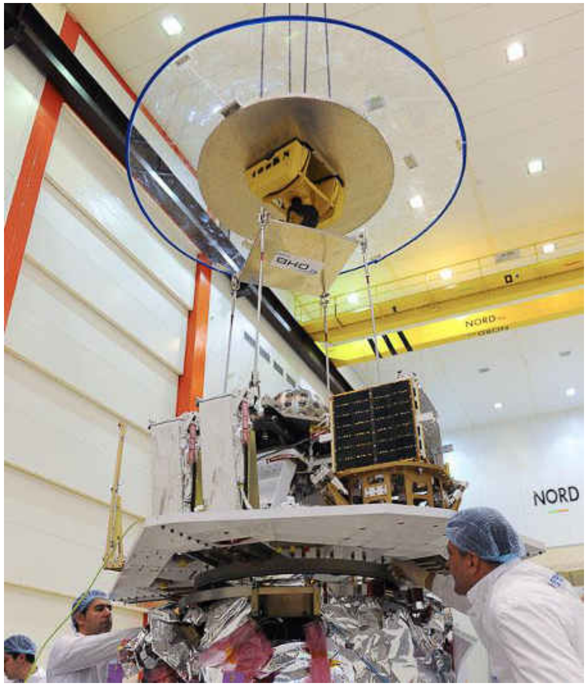




UNIBO students in SPACE

ALMA*Sat-1* microsatellite was entirely designed, manufactured and assembled in the Microsatellites and Space Microsystems Lab of the University of Bologna in Forlì.

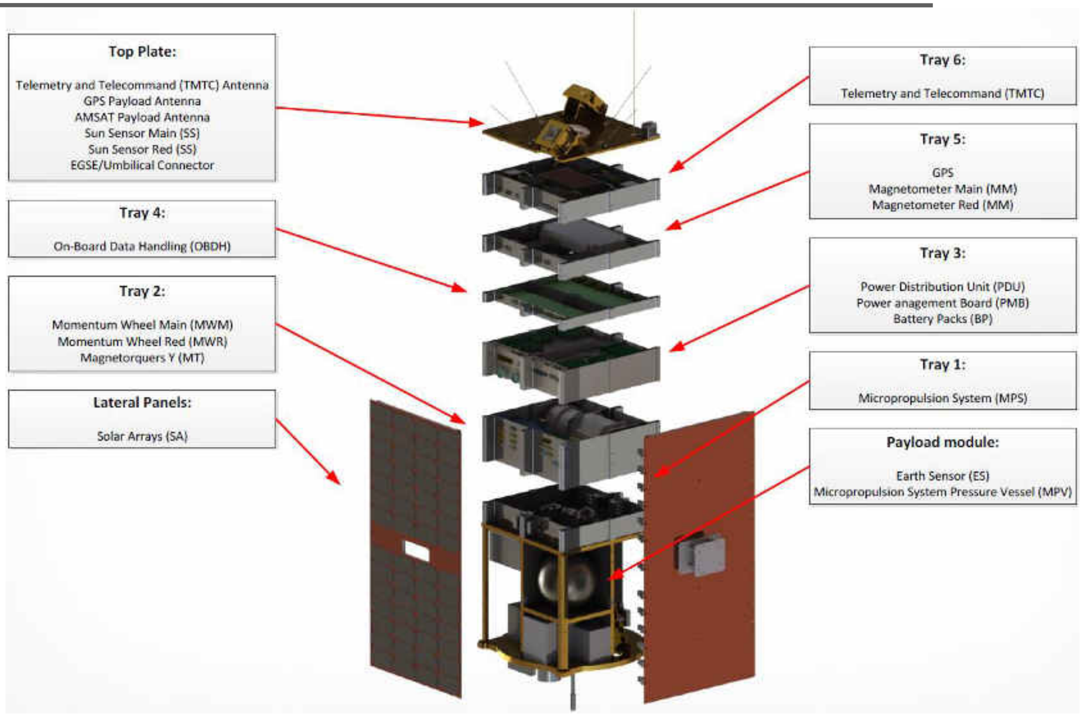




European Student Earth Orbiter (ESEO)

ESEO is a micro-satellite mission of the European Space Agency (ESA) Education office.

ESEO will be launched into SS LEO in 2017 (TBC) and will orbit the Earth taking pictures, measuring radiation levels and testing technologies for future education satellite missions.



SITAEL (formerly ALMASpace) is the prime contractor for the platform whilst UniBO is responsible for the on-board GPS receiver, TMTC primary GS and MCC. After successfully passing the PDR and CDR, the project is now in phase D.

Mass	50 Kg
Altitude	523 km
LTAN	10:30
Attitude	Nadir pointing
Dimension	33x33x63 cm

ESEO Educational Activities

- Lectures, Training Courses and Internship opportunities were organised and conducted at system level at the UniBO and System Prime premises for 60 students selected from University Network.
- About 200 students are collaborating to ESEO at different levels of involvement, most of them from the premises of all university teams involved in the project.
- In January 2015 the last group of ESEO students joined UniBO and SITAEL for their internship period.

University of Bologna
GPS Receiver, UHF Ground Station #1 (GSF)
Mission Control Centre (MCC)

Hungarian Academy of Sciences
Tritel Dosimeter (TRITEL)

Technical Univ. of Munich
S-band Ground Station (GSM)

Wroclaw Univ. of Technology
S-Band TX (HSTX)

University of Vigo
UHF Ground Station #2 (GSV)

Budapest University of Technology and Economics
Langmuir Probe (LMP) &
Power Distribution Unit (PDU)

Cranfield University
De-Orbiting Mechanism (DOM)

Tartu Observatory
Optical Payload (CAM)

AMSAT-UK
Educational HR Payload (AMSAT)

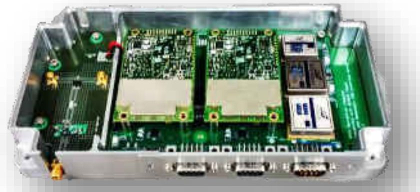
Technical Univ. of Delft
ADCS S/W Experiment (ADE)

Ph. Nani Serrano

Current SmallSat Activities @ UNIBO

- Following the re-organization of its industrial branch (ALMASpace), the Microsatellites and Space Microsystems Lab at University of Bologna is now focusing on the following target areas:
  - Micropropulsion systems
    - Cold-gas (Nitrogen):
      - Flown on ALMASat-1 in 2012 (not tested)
      - To be flown under a different system configuration on ESEO (developed by **SITAEL** with **UniBo** support)

    - Monopropellant (warm-gas), under development, jointly with **SITAEL** and **FBK**
  - GPS Receivers and Autonomous Navigation Systems
    - To be flown on ESEO, as part of the payload package, in collaboration with **SITAEL**



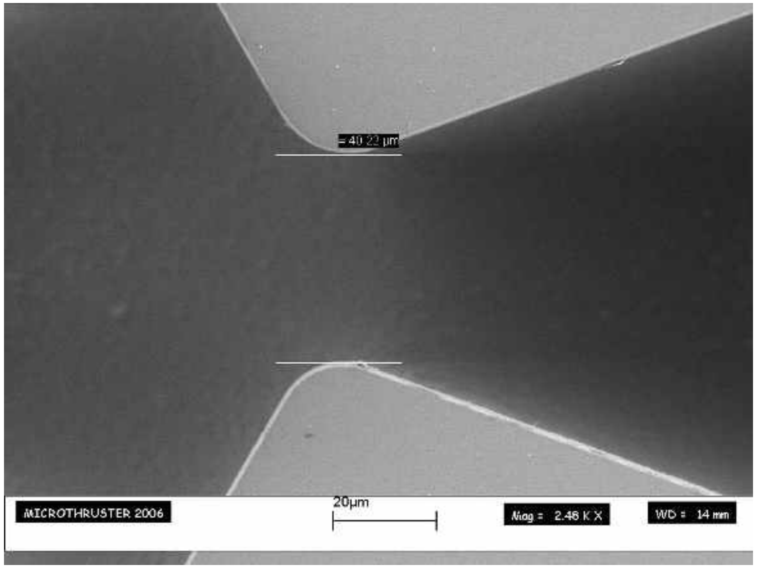
  - Ground Segment/Station Technologies and Mission Control Centers
    - UNIBO is responsible for the ESEO Ground Segment

Missions & Space Technologies

A) Micropropulsion

ALMASat-1 Cold-Gas μprop system

- Gaseous Nitrogen Propellant, pressurized in a tank, flowing through a De-Laval nozzle
- MEMS-based micronozzles (L throat = 40μm) with thrust ≈ 1 mN
- Applications: attitude and orbit control
- Same concept re-adapted for ESEO mission



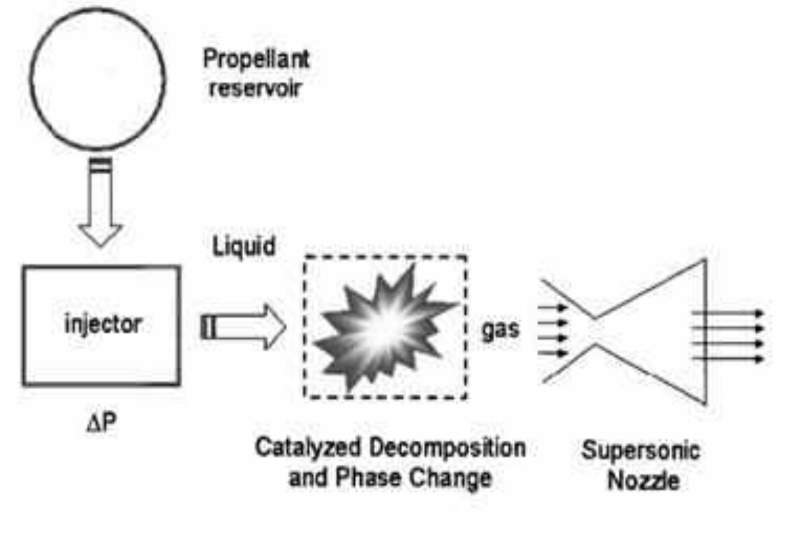
Microscope image of the nozzle throat area (courtesy of CNR Bologna)

ALMASat-1 Cold gas μ-propulsion system

- **Pros:** simple fluidic layout, possibility to set target thrust at extremely low levels
- **Cons**: Low specific impulse (≈ 60 s) and limited total impulse (attainable ΔV) due to low storage density

Monopropellant (Warm-Gas) μprop system

- Under development under joint collaboration with SITAEL and FBK
- Based on exothermic catalytic decomposition of $H_2O_2 \rightarrow \frac{1}{2} O_2 + H_2O$ (green!)
- High concentration H_2O_2 propellant produced in-lab
- MEMS-based device, integrating a catalytic chamber and a micronozzle in a single unit



Monopropellant system working principle

MEMS-based microthruster prototype manufactured at FBK premises

- **Advantages wrt Cold-Gas**: High Specific Impulse ($\approx$ 150 s), propellant with high density storage (lower storage volume)
- **Disadvantages**: more complex system (management of the liquid propellant, possible pre-heating of the device, ignition time)

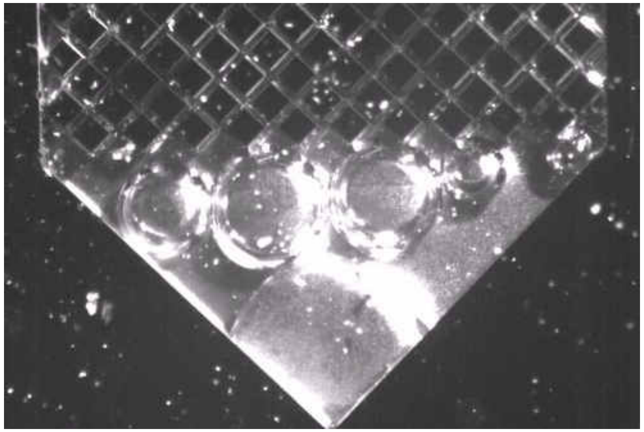
H_2O_2 μthrusters prototype testing

- A first batch of prototypes were tested with in-lab distilled H_2O_2, injected through a syringe pump
- Only an incomplete propellant dissociation was achieved in the chamber:
  - A bubbly gas-liquid mixture is found at the nozzle rather than the expected warm gas stream
- SEM pictures of samples sections showed that catalyst deposition was not uniform all over the device.
- Indications of the need for:

  a) improved catalyst deposition process, and

  b) deeper insight into complex interactions within the reacting multiphase flow.

Preliminary Thruster sizing geometric parameter and target performance	
Throat Sizer: Dt	40 μm
Constant Height: H	320 μm
H_2O_2 initial concentration: %	87.5 %
Adiabatic Temperature: T	949 K
Mass flow rate: $\dot{m}$	≈ 1 mg/s
Thrust: F	≈ 2 mN
Specific Impulse: Isp	150 s



End of the decomposition chamber and nozzle convergent region showing the "bubbly flow " operation

Missions & Space Technologies

B) GPS-Based Navigation system for satellite missions

ESEO GPS Payload

MISSION TARGETS

- To verify in space environment the functionality of **commercial technologies**, commonly used in terrestrial GNSS receivers
- To develop and test of a **sophisticated navigation algorithm**, in order to determine the positioning accuracy achievable by a commercial receiver on board of a satellite.

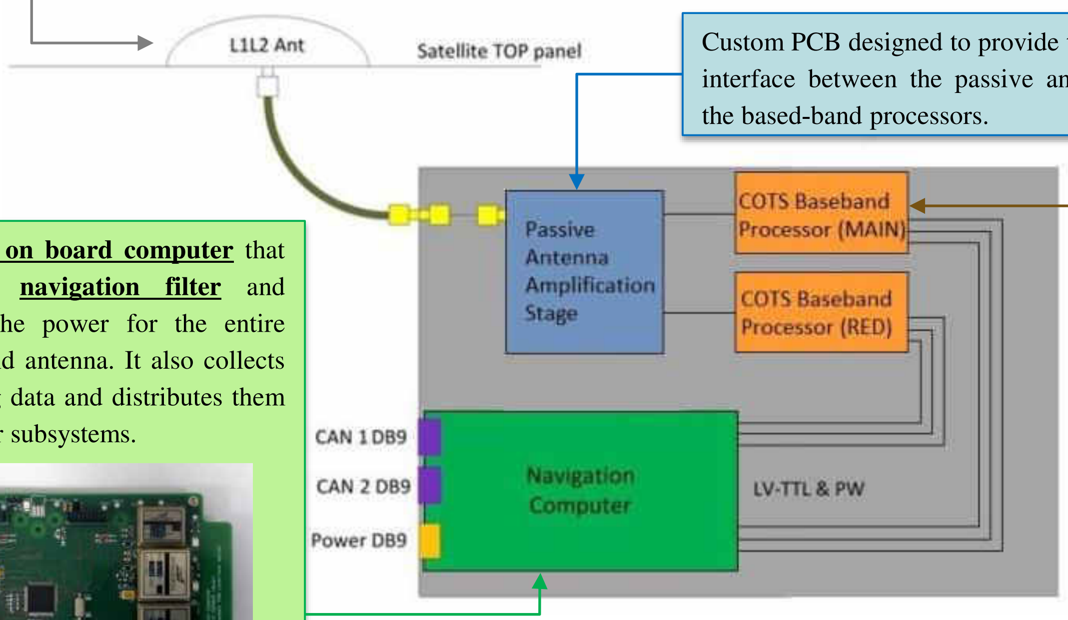
NAVIGATION FILTER DESIGN

Two different algorithms will be hosted on board of the payload:

- **Kinematic solution:** a direct computation of the receiver position from the raw observables, without filtering it by an orbit dynamic model. The provided accuracy is the typical accuracy of ground application, between **10-15 m 3D RMS**. The method used to determine the position is based on **Least Square Algorithm.**
- **Reduced dynamic solution:** this algorithm is based on the integration of the raw observations within an accurate orbit dynamics model, using an **Extended Kalman Filter**. According to the complexity of the model and to the observation combination, this algorithm 3D RMS accuracy is between **60 and 80 centimeters**.

Functional Architecture

A passive antenna from Sensor Systems **with flight heritage**, model S67-1575-20, mounted on the satellite top panel.



Custom PCB designed to provide the correct interface between the passive antenna and the based-band processors.

A **custom on board computer** that hosts the **navigation filter** and manages the power for the entire payload and antenna. It also collects positioning data and distributes them to the other subsystems.

Two **OEM615 receiver**, from **Novatel**, in **cold double redundancy,** that performs GPS signal acquisition, tracking and data demodulation. It provides the raw GPS measurements together with the GPS satellite broadcasted navigation data that is required to compute the navigation solution. COCOM limitations removed.

Test and Verifications

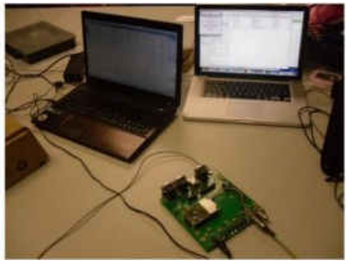
<u>Recursive Filter test:</u> in order to <u>verify the performance of the navigation algorithm</u> in a real scenario, it was implemented and used to process GRACEA raw observations.

<u>Results:</u> The off-line processing showed a positioning error of about 80cm 3D RMS when using broadcasted GPS ephemeris and clocks. It is expected that the ESEO positioning error will be worse, between 1 and 1.2 meters, due to the lower quality of the receiver oscillator.

<u>Baseband Processor Test:</u> a functional test was performed at the ESA/ESTEC facilities using a GPS signal simulator, in order to ensure that the receiver is suitable for operations on-board the satellite. Mission scenario simulated to verify functionality with typical space doppler values.

<u>Results:</u>

- need for an initial forced setting of the receiving channel's frequency scanner (to space Doppler values),
- obtained mission data consistent with the simulation scenario.



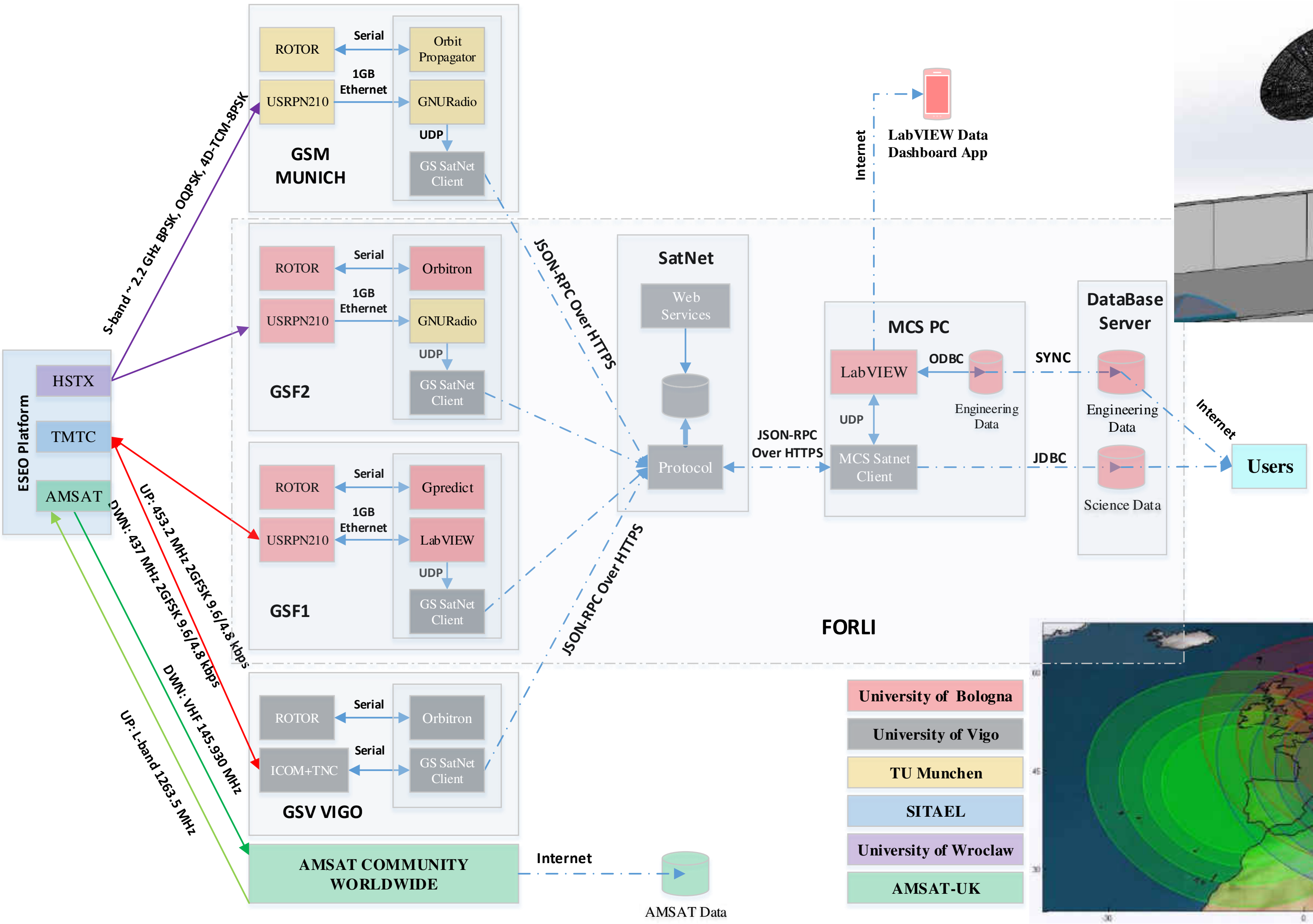
<u>Communication test</u>: full functional test performed on the payload in "flight configuration" in order to verify the correct hardware and software implementation of the communication between the microcontroller of the custom PCB and the COTS front end.

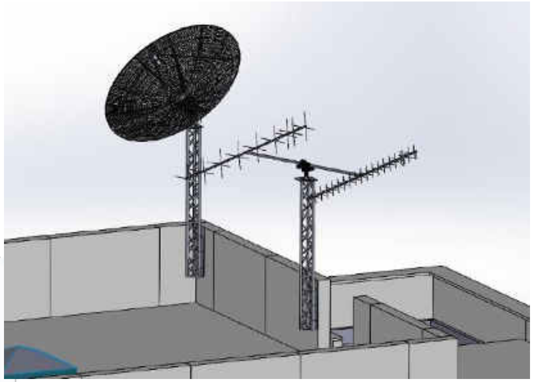
<u>Thermal test</u>: performed to assess the functionality of both the COTS baseband processor and the custom navigation computer under external thermal conditions close the ones experienced in orbit. The thermal chamber was set first to -25° and then to 70°, and in both cases an electrical and a functional tests have been performed.
<u>Results:</u> no critical degradations of the performances occurred under extreme external conditions.

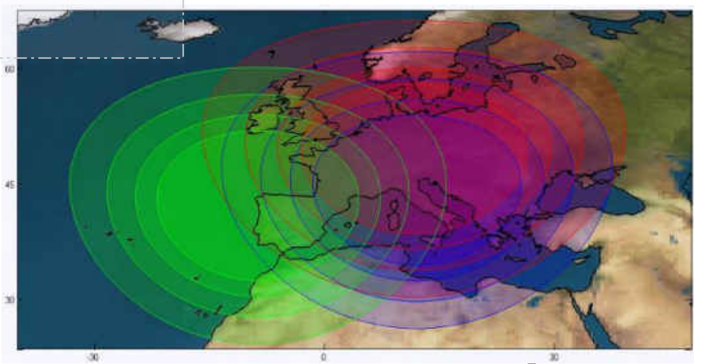
Missions & Space Technologies

C) Ground Segment

ESEO Ground Segment and Ground Station Network







SDR based Ground Station

SDR technology allows students to have hands-on experience on digital communications and better understand the theoretical principles behind modulations schemes and communication protocols.

TX:

- Digital to Analog Conversion
- RF Upconversion

RX:

- RF Downconversion
- Analog to Digital Conversion

TX:

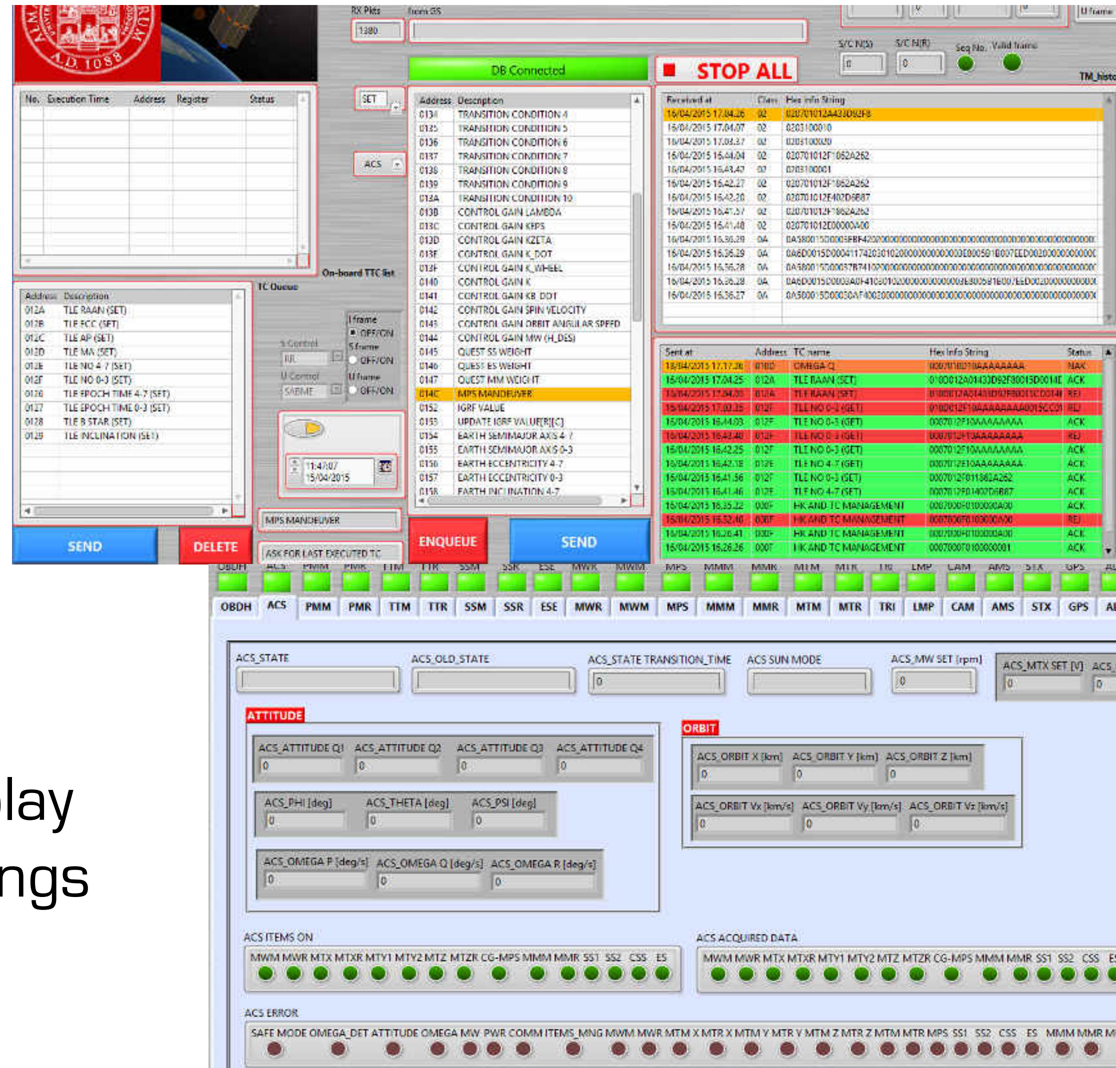
- Modulation
- AX.25 encoding
- BB transmission

RX:

- Signal Display (Spectrum, Waterfall, ..)
- Signal Recording
- Demodulation
- AX.25 decoding

ESEO M&C System

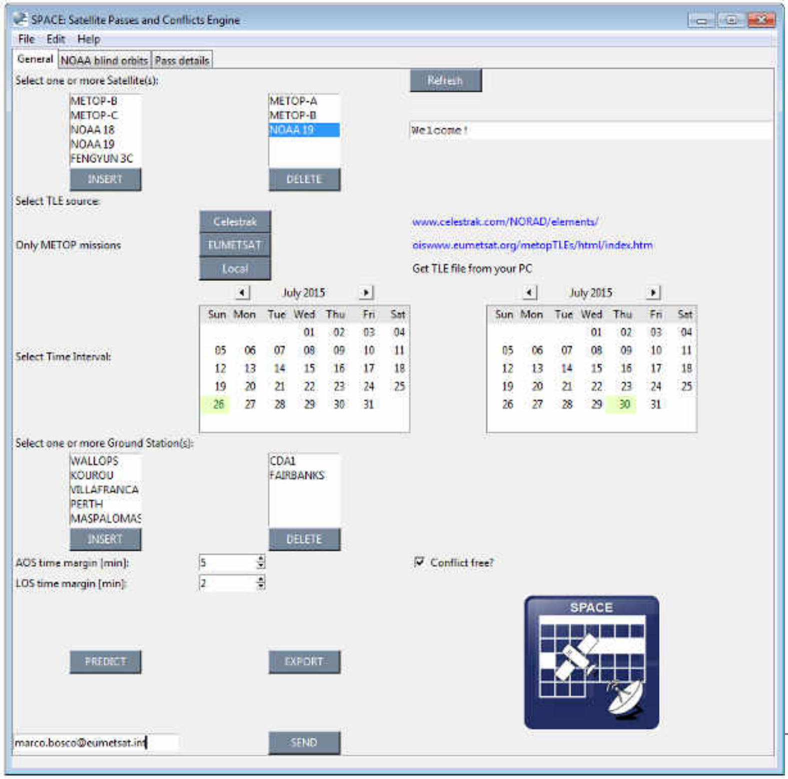
- Connected to the S/C Database
- TC selection
- TC stack
- TC acknowledgments



- TM packets display
- TM data display
- On-board schedule display
- Automatic e-mail warnings
- TM playback

Satellite Passes and Conflicts Engine (SPACE)

- Satellite passes over GS
- Conflicts detection and resolution of passes based on GS priority list.
- Results are displayed as html pages.
- TLE propagators are open-source Python libraries: *pyorbital* and *pyephem.*
- TLE can be retrieved from internet (CelesTrack) or from local.
- Azimuth dependent horizon mask can be added as CSV files.

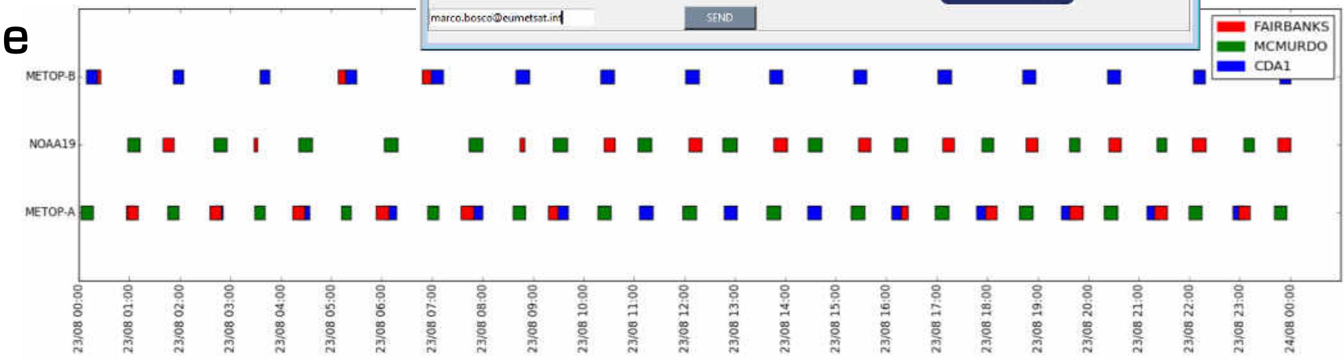


Conflict-free pass schedule

three S/C (y-axis)

over three G/S (legend)

for one day (x-axis)



Thank you for your attention!

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µProp status and roadmap

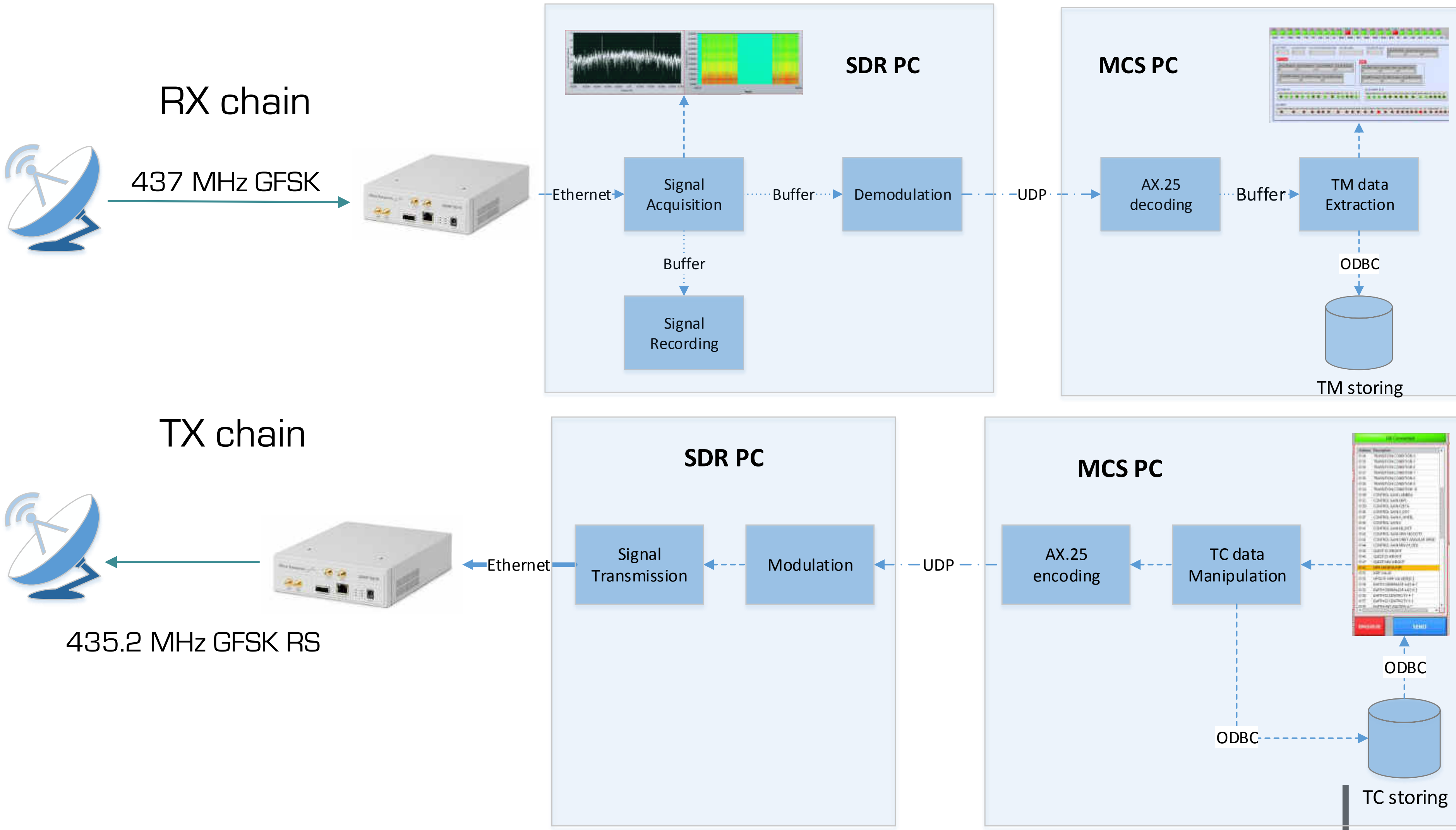
- Cold gas N_2 µProp system is reaching a high maturity level, expected in-orbit testing onboard ESEO S/C.
- Current efforts focused towards H_2O_2 monopropellant, encompass several areas:
  1. MEMS design and manufacturing
  2. Catalytic decomposition kinetic experimental tests
  3. Numerical modelling
- Tests over first batch of prototypes revealed only a partial degree of decomposition calling for a deeper insight into the catalytic decomposition.
  1. Decomposition kinetic studies (currently in advanced state)
  2. Full 3D FEM model for the *biphase-chemically reacting-evaporating* flow around pillars (currently in advanced state)
  3. Manufacturing: improved design and catalyst deposition in a reproducible and controllable way (under preparation)
- Next generation of thruster prototypes expected to be ready for testing in the next few months.

ESEO GPS Payload

Educational content
Opportunity for students to directly **face problems and issues** that may rise during the design of subsystems for **real space missions**
Training for students in order to **conform their work to the quality standards of ESA missions**, thanks to the frequent reviews to which the payload is subjected.

Technological content
• **low-cost solution** for GPS positioning in space
• **high quality data**

Forlì TMTC GS + S/C M&C



Mission Control Room and Antennas

- VHF/UHF Yagi antenna (144-146, 430-440 MHz).
- S-band antenna (CCSDS frequency ranges)
- Downlink and uplink operations
- Dedicated mission control room

Students will learn by following and performing satellite operations.