ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ADCSS2024

22 - 24 October 2024, ESTEC – The Netherlands

Ground-test facility for CubeSats attitude determination and control: the University of Bologna experience

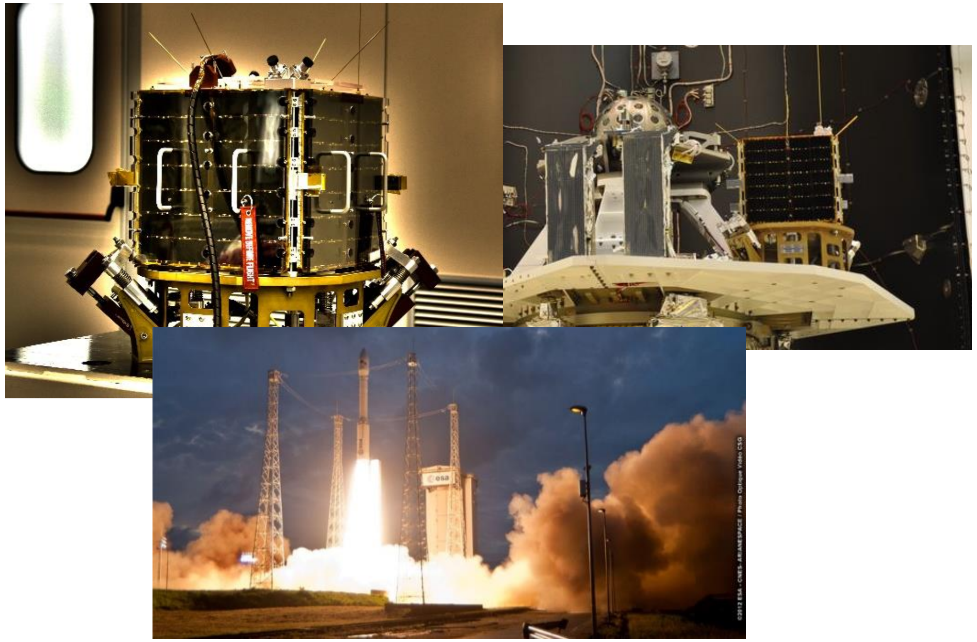
Dario Modenini

on behalf of the CubeDynA team

Andrea Curatolo, Daniele Pecorella, Giacomo Curzi, Alessandro Lotti

Background

µ3S Lab – µSatellites and Space µSystems Lab



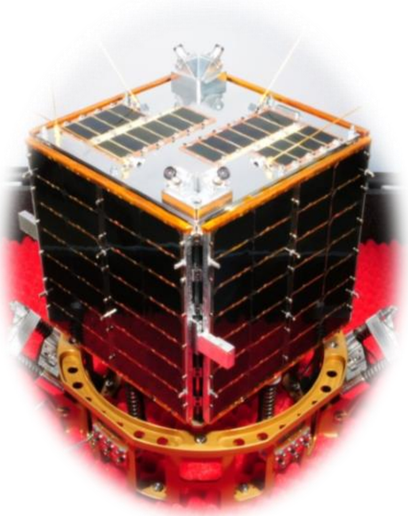
Technology Developments

- *Microsatellites*
- *Spacecraft Subsystems*
- *Micropropulsion*
- *GNSS Receivers*
- *Ground Station Technologies*
- ***Ground Testing equipment***

ALMASat (ALma MAter Satellite)

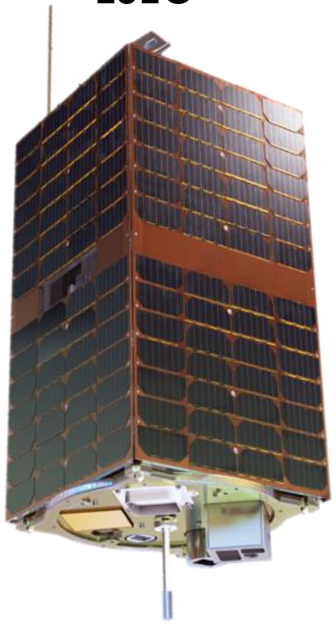
- *Technology Demonstrator*
- *Micropropulsion and Trasmission Experiments*
- *Launch: 17 Feb. 2012*

ALMASat-1



Launched 17-02-2012
(UniBO)

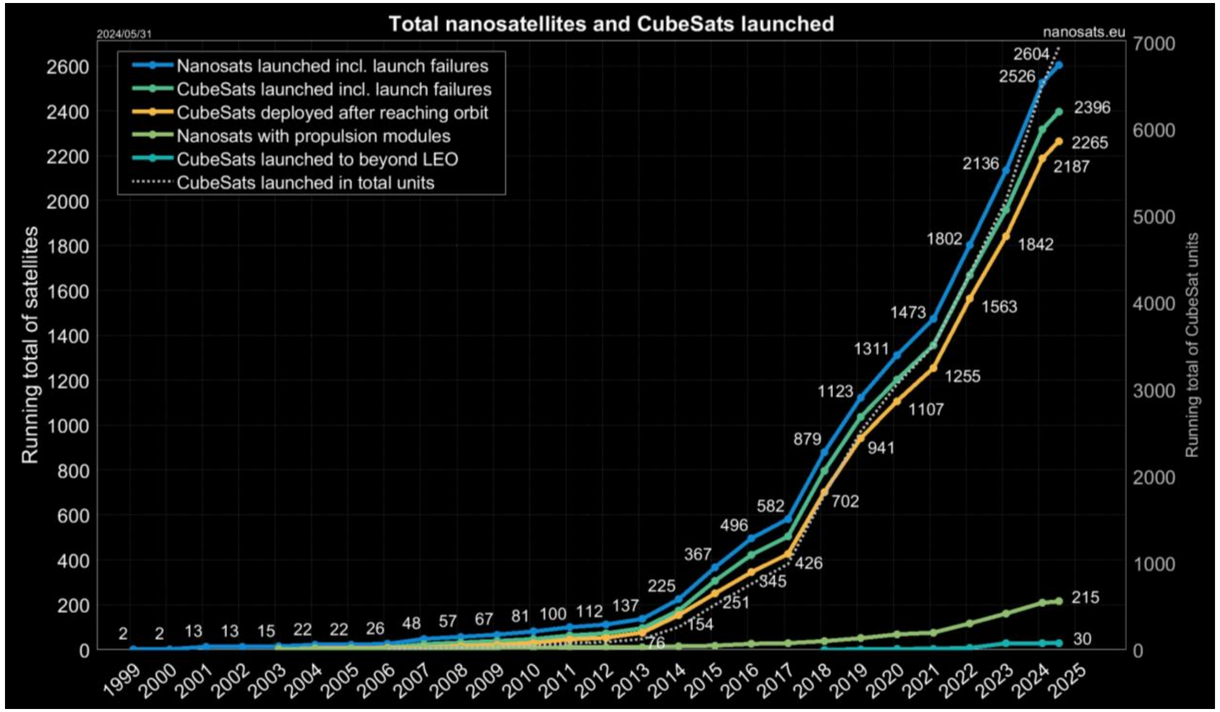
ESEO



Launched 03-12-2018
(ESA – SITAEL)

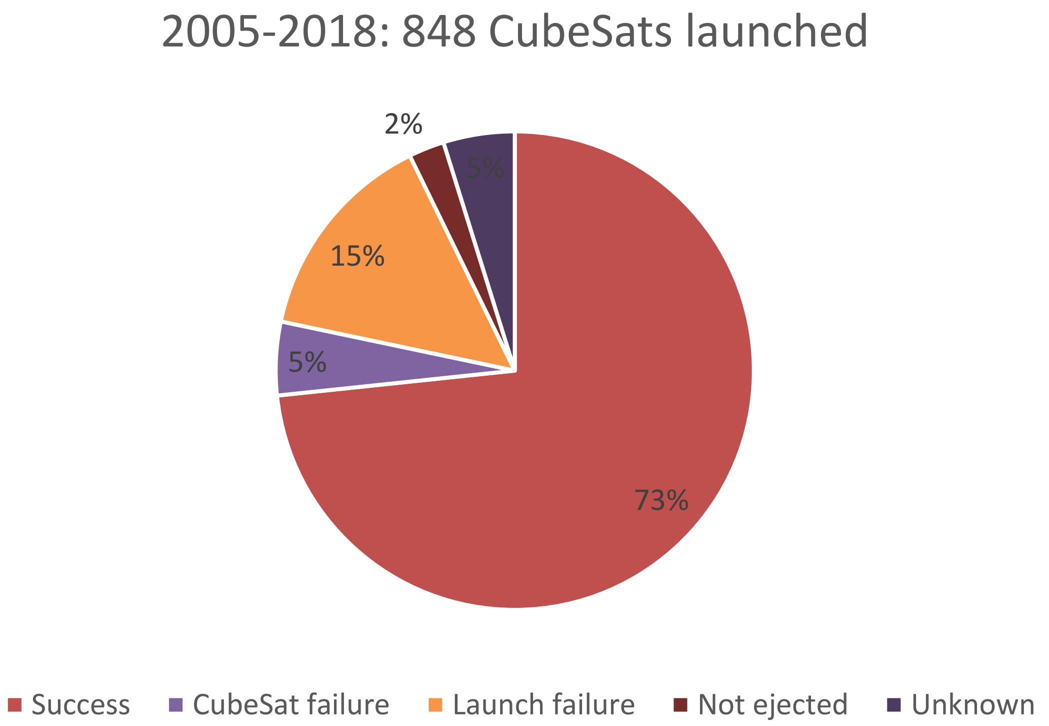
Motivations

More and more CubeSats launched



Credit: E. Kulu, Nanosats database." Available at https://www.nanosats.eu/

Still high failure rate

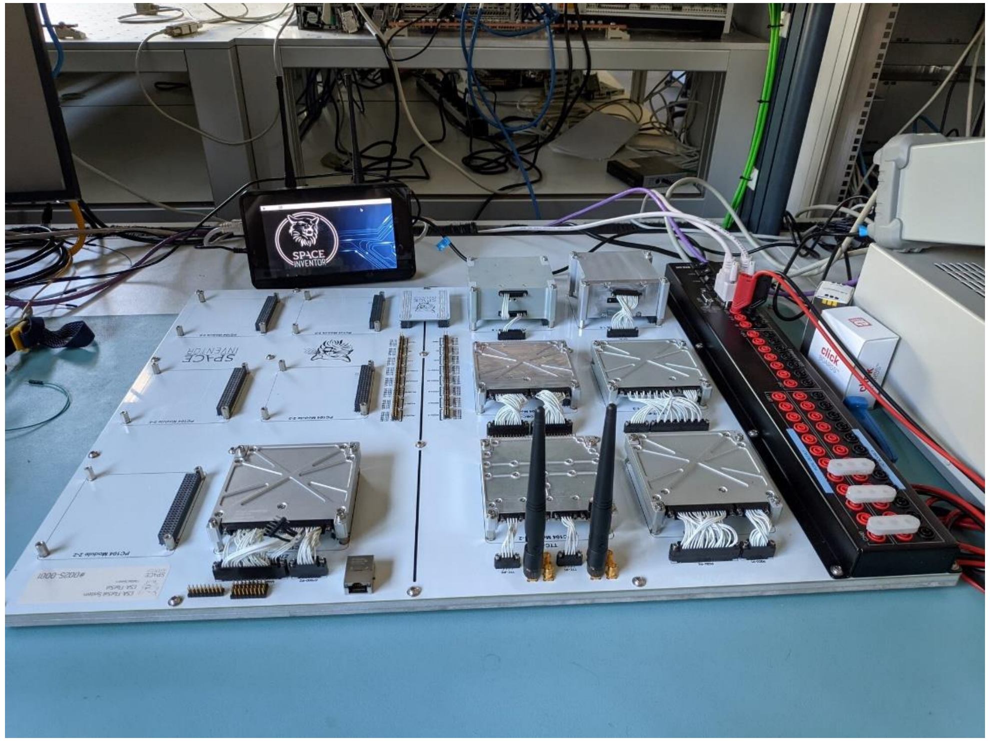


Credit: T. Villela, C. Costa, A. Brand~ao, F. Bueno, and R. Leonardi, “Towards the thousandth cubesat: A statistical overview," International Journal of Aerospace Engineering, vol. 2019, pp. 1-13, jan 2019.

MICROSATELLITES AND SPACE MICROSYSTEMS - LABORATORY -

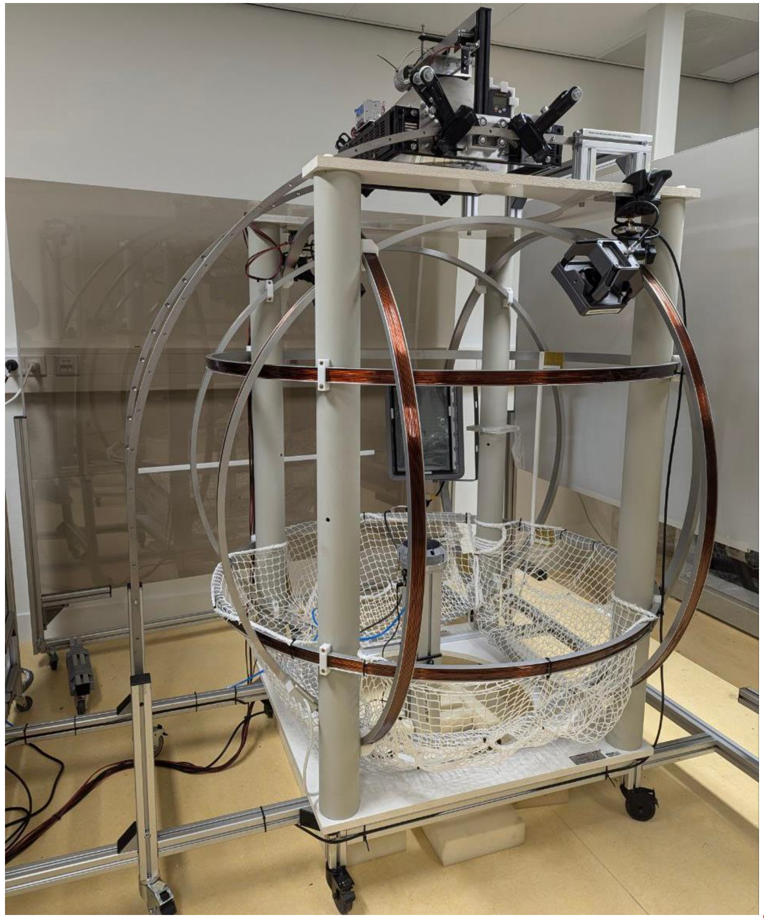
ADCS Testing approaches

“Flatsat” approach



Credit: ESA

“Test-as-you-fly” approach



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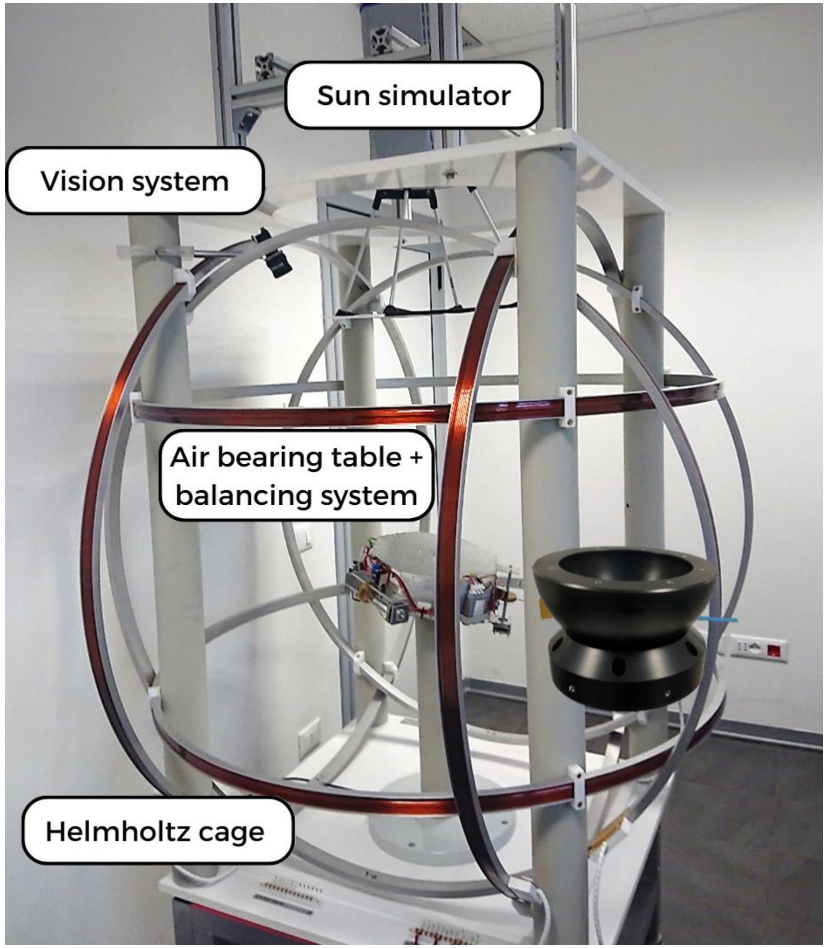
CubeSat-class ADCS testing facility

A CubeSat-class ADCS testing facility @ UniBo

Microsatellites and Space Microsystems Laboratory

CubeDynA - MK1



@ u3S Lab – Università di Bologna

- Developed at u3S Lab Università di Bologna since 2017
- Based on **table-top air bearing**, payload capacity ≈ 5 kg
- COTS **triaxial Helmholtz cage** for in-orbit magnetic field simulation
- Fixed height pedestal to support the air-bearing table
- **Automatic mass balancing** system with shifting masses
- Fixed, LED-source **Sun simulator**
- Monocular ground truth **vision system** developed in-house ≈ 0.3° accuracy

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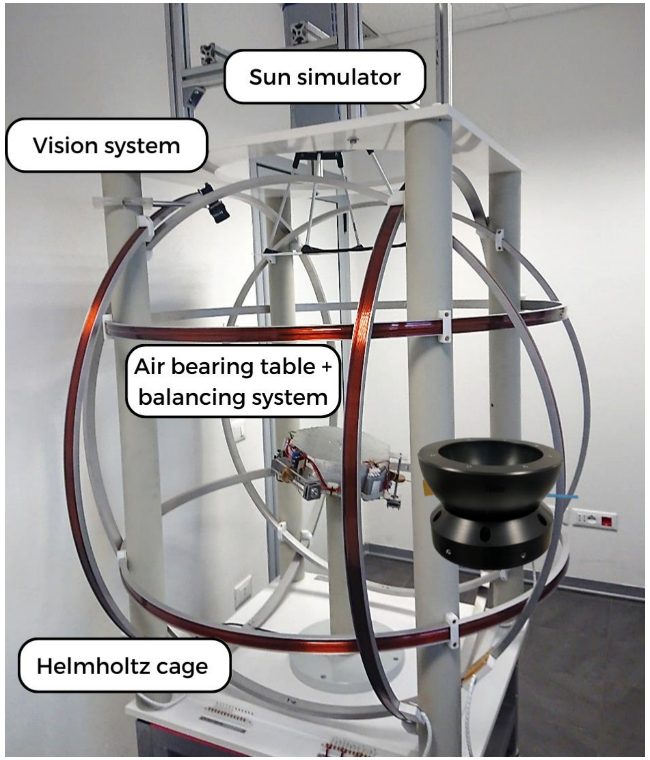
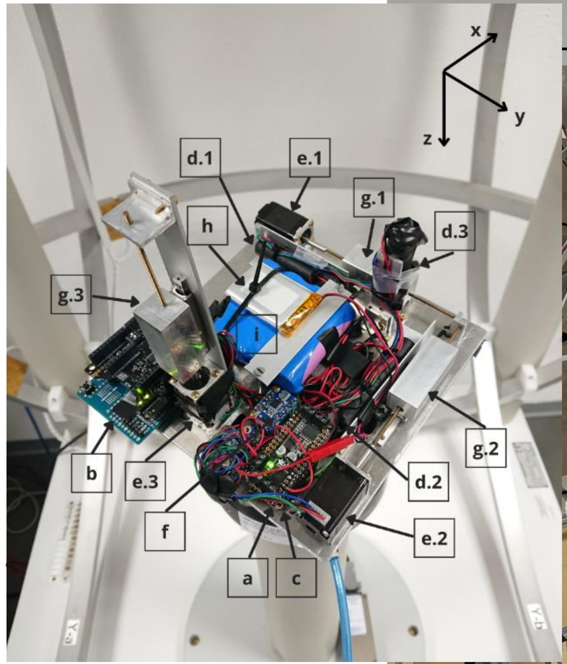
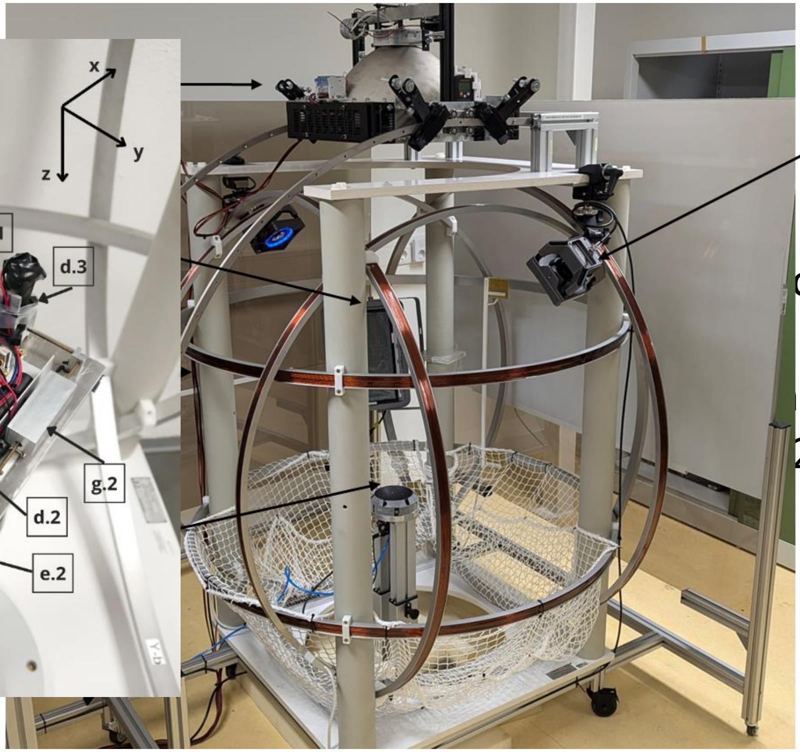
CubeDynA evolution

CubeDynA - MKI (2017)



CubeDynA - MKII (2024)

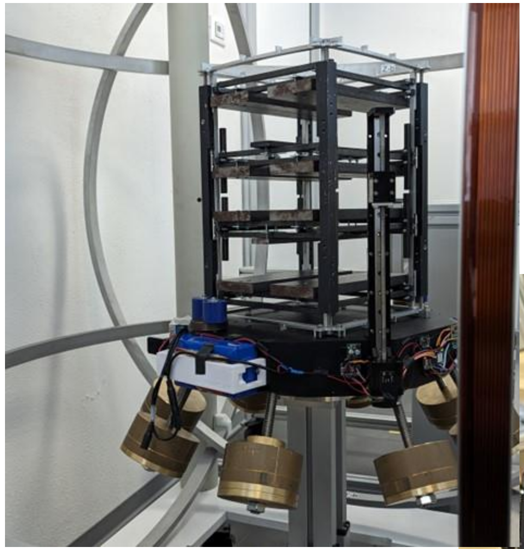


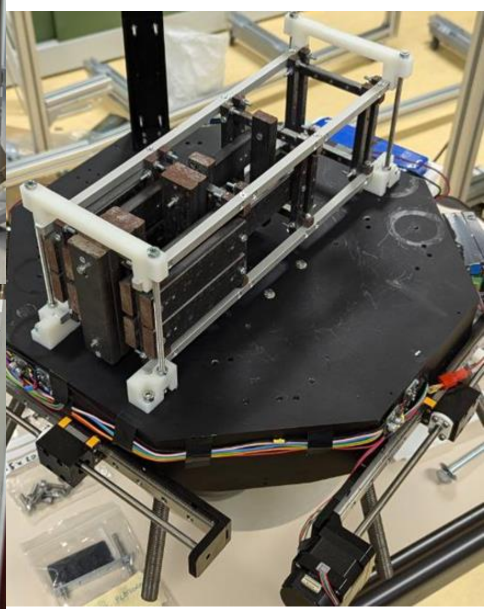


CubeDynA MKII is installed in ESTEC Room EA024 – AOCS/Pointing Lab
Technical Officer: Andrew Hyslop

CubeDynA MKII features

- **Suitable to test 1U, 3U, 6U and 12U CubeSats in any orientation and with sizes, mass, CoM position specified by the CubeSat standard**
- **Standardized mechanical interfaces**
- 2 support platforms with auto-balancing system through shifting masses
- Mountable battery pack to supply the hosted CubeSat with up to 30 W for 3 hrs at a DC-regulated voltage of 8, 12, 16, 18, or 24 V
- Communication module with CAN and I2C to bi-directional TMTC relaying with ground station
- Simulated Sunlight with different beta angles via movable sun-lamp
- Metal Halide Lamp for improved Sunlight spectral matching
- COTS ground-truth system for independent attitude estimation and optionally emulate star tracker – accuracy ≈ 0.1°
- Compatibility with ISO 8 class clean room/tent





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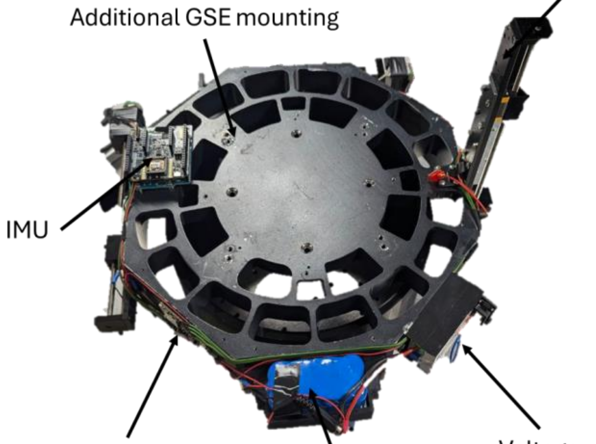

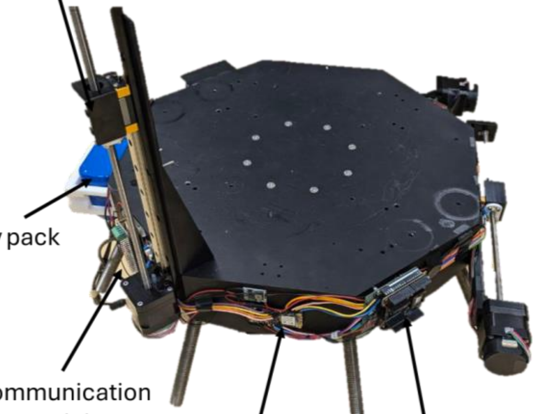

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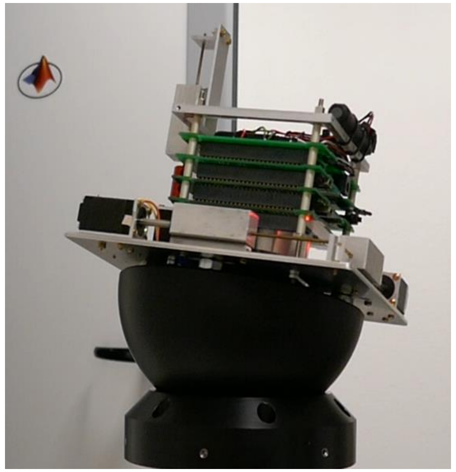
Use Cases

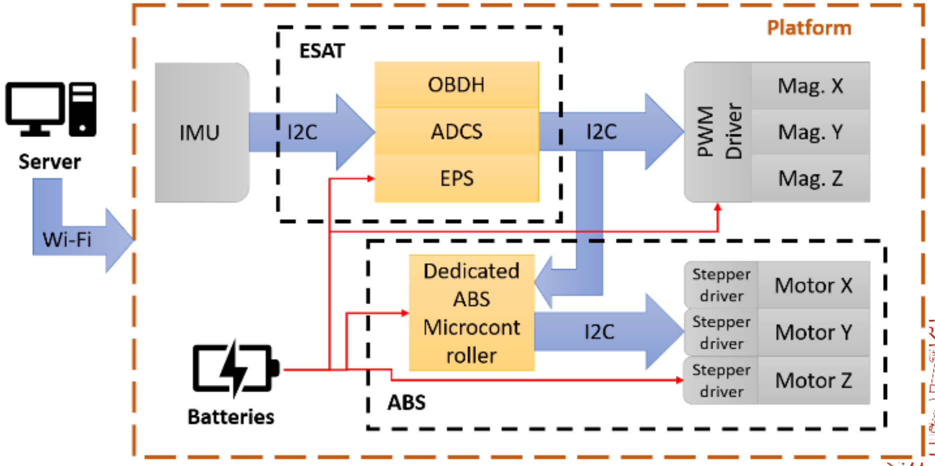
Use Case 1: ADCS HW/SW R&D

Magnetic-only attitude control experiments on a dedicated mock-up equipped with magnetorquers and mass balancing system

- Magnetic detumbling
- Spin-axis pointing
- Three-axis pointing



Magnetic field	• 0.2% dynamic error • 2% uniformity
Principal inertia moments	• $[9.98, 10.12, 9.41] \cdot 10^{-3}$ [kgm^2]
Residual disturbance torque	• max $\|\|T_d\|\| < 5 \cdot 10^{-5}\ Nm$ • RMS $\|\|T_d\|\| < 2.5 \cdot 10^{-5} Nm$

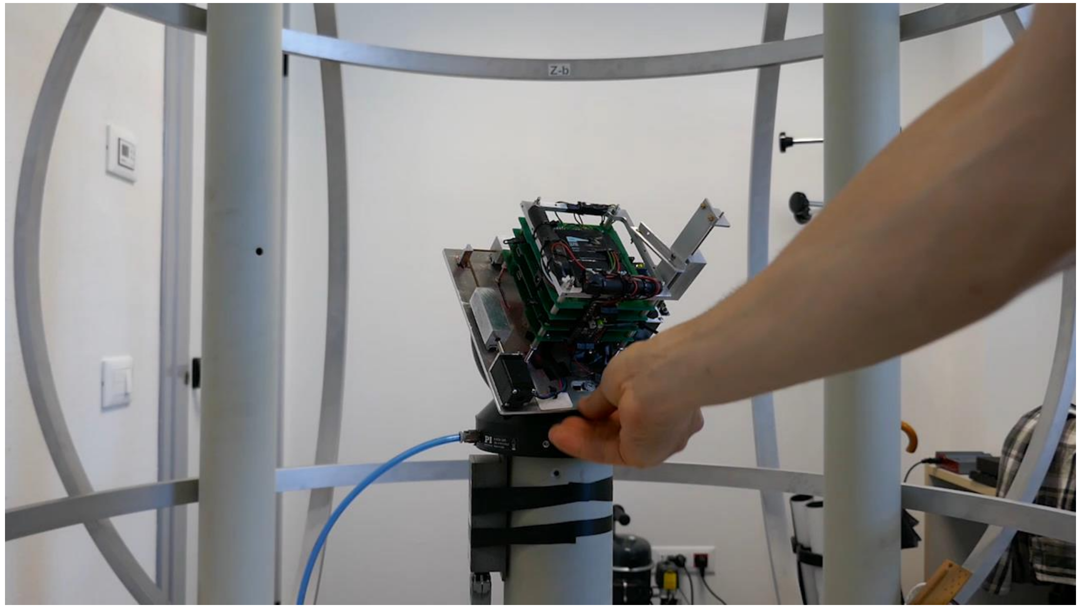


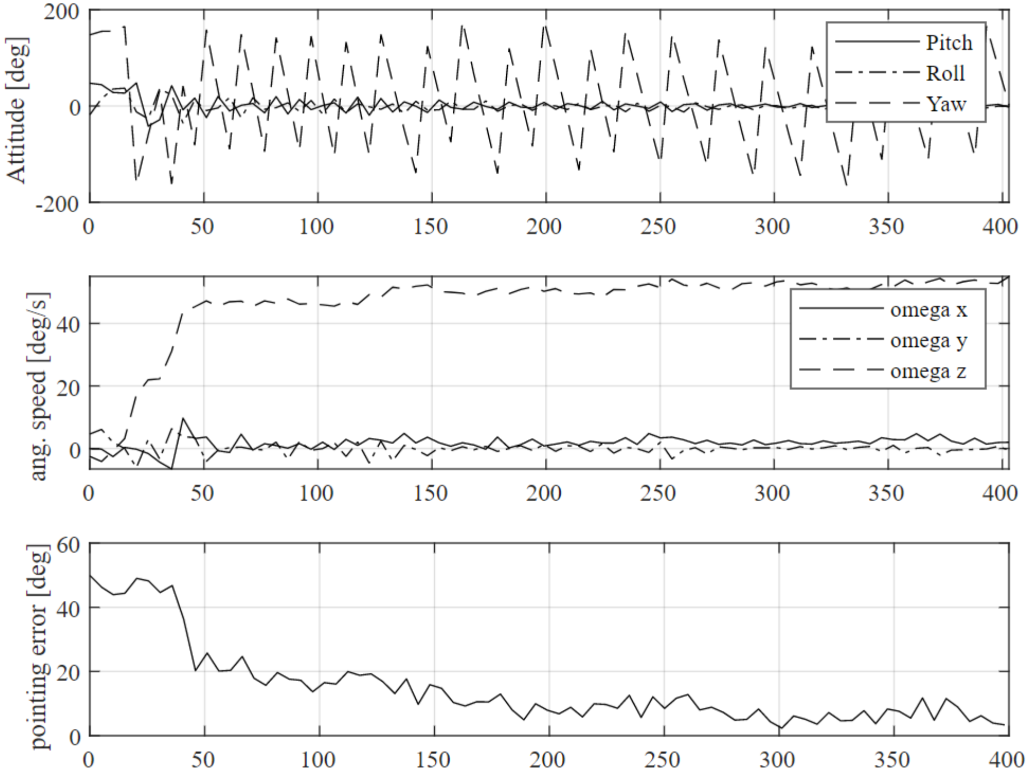
Use Case 1: Spin axis pointing

- LEO with the desired spin axis aligned to local vertical = orbit plane normal
- Target angular rate of 1 rad/s
- Steady state is reached in 150 seconds
- The pointing accuracy is ≈ 5°

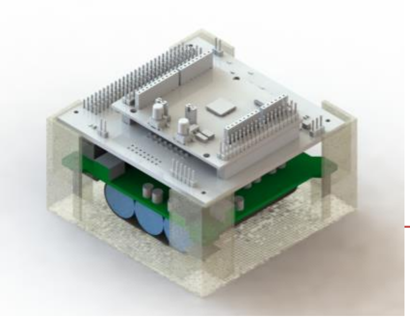
$$\boldsymbol{m} = \boldsymbol{b} \times \left(k_1[\omega_1, \omega_2, 0] + k_2[0,0, h_3 - h_{3ref}] + k_3 \Delta \boldsymbol{h}\right)^{**}$$

** from "A fault-tolerant magnetic spin stabilizing controller for the JC2Sat-FF mission", de Ruiter, A.





Application - 2: testing third-party Cubesat ADCS mock-up



Cubesat Mock-Up
@ STAR Laboratories, PoliTo

Cubesat's ADCS Test in CubeDynA Facility
@ u3s Laboratories, UniBo

CubeDynA Facility
@ u3s Laboratories, UniBo

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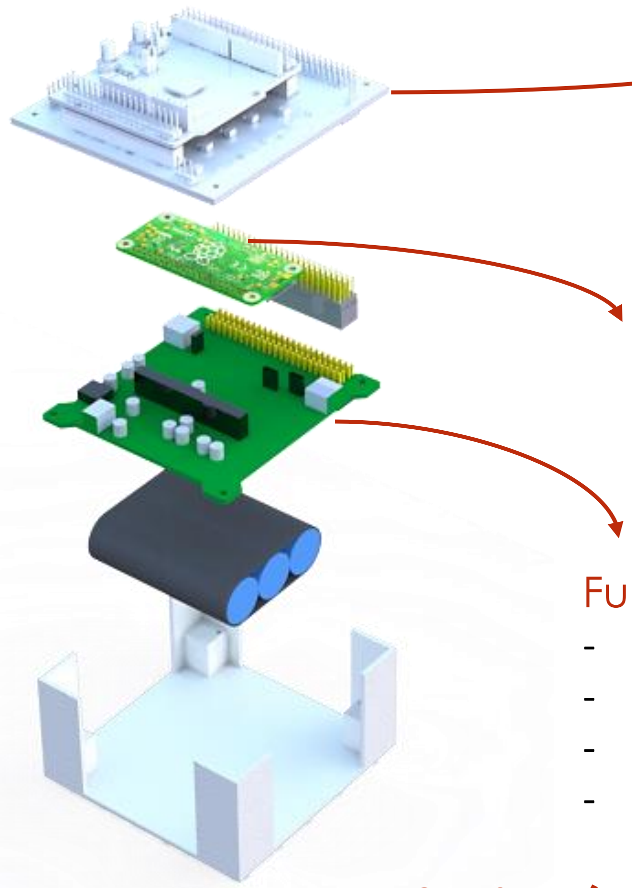
Cubesat Mock-Up: ADCS and Functional Board

Microsatellites and Space Microsystems Laboratory



ADCS Board + NUCLEO Board

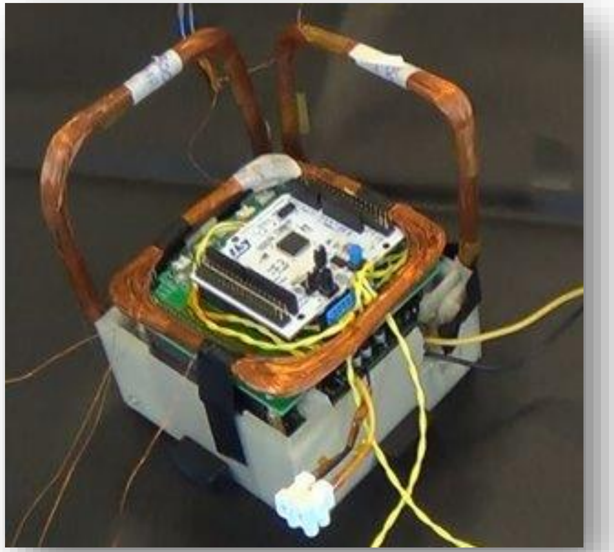
- Manages Comms with Functional Board via UART
- Acquire Measurements from Sensors
- Runs Control Laws for Detumbling
- Commands the Actuators

Raspberry Pi Zero

- Provide the WiFi Module for Comms between Ground Station and the Functional Board

Functional Board

- Provide Regulated Voltages from the Battery Pack
- Allows the Battery Pack Recharge (without removing it)
- Control and Data Handling (CDH)
- Synchronize Comms between Ground Station and ADCS Board



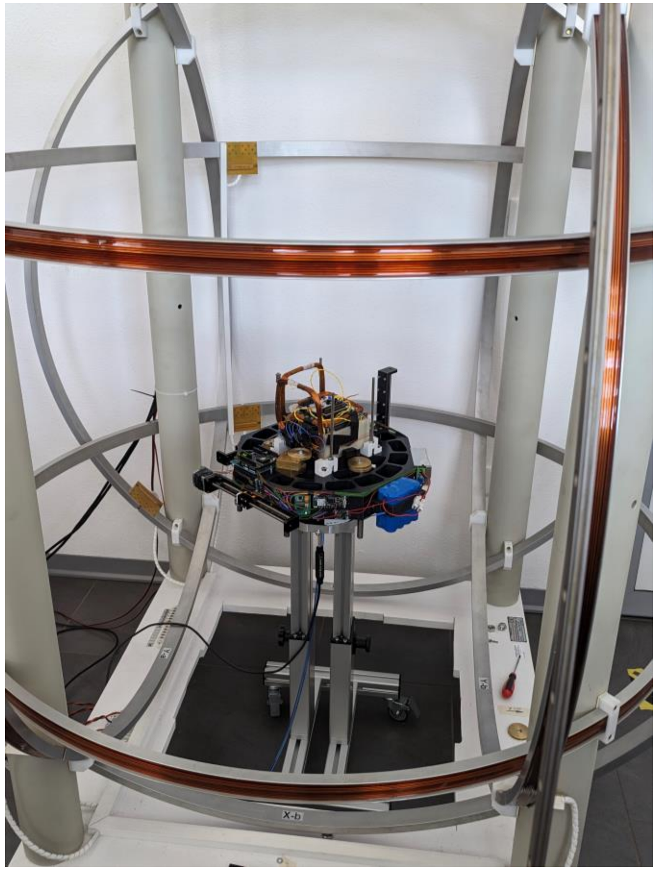
Politecnico di Torino

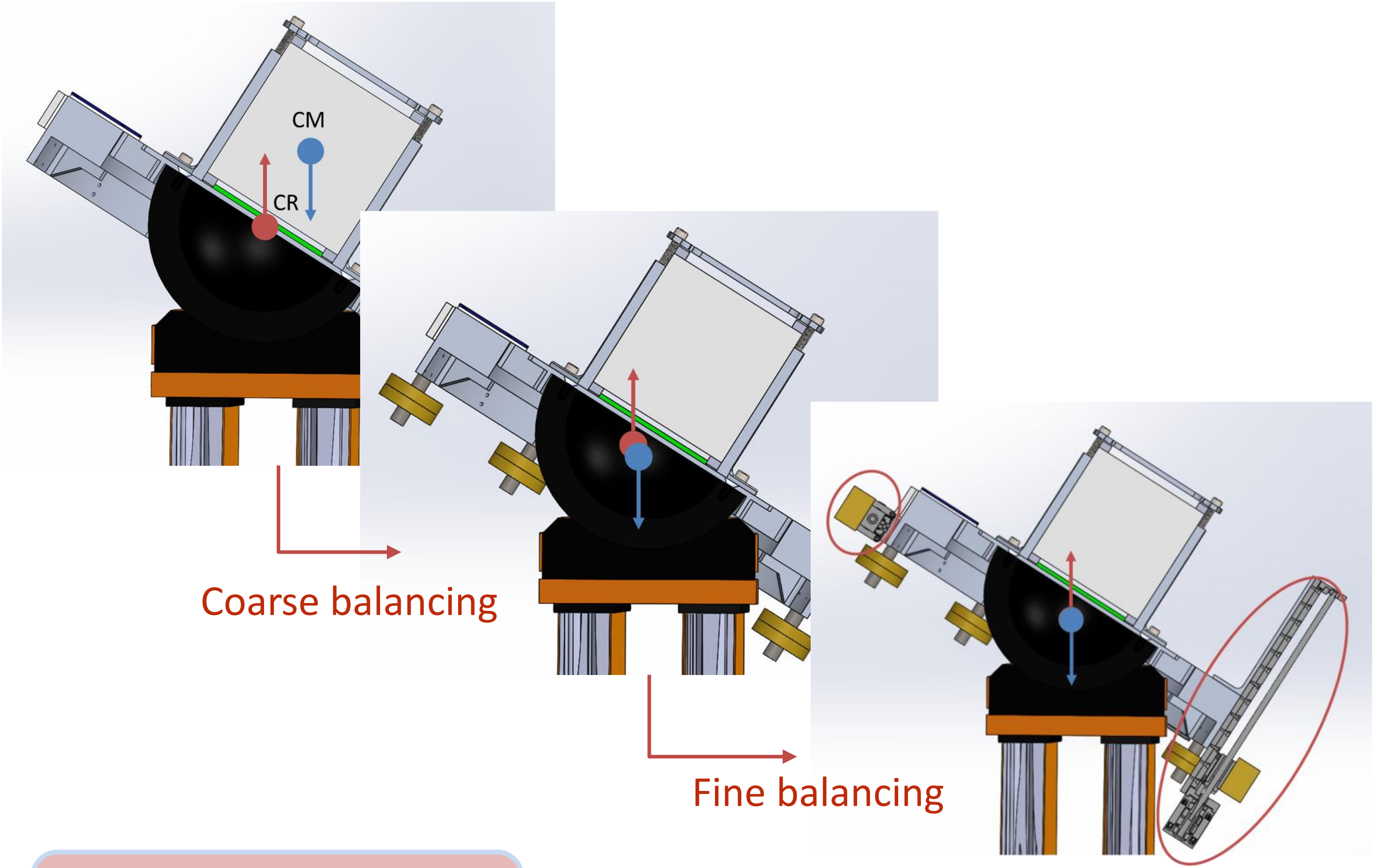
3 MSc Theses

6 students involved

Alma Mater Studiorum Università di Bologna

Integration and test campaign





Platform integration and mass balancing

Actuation test

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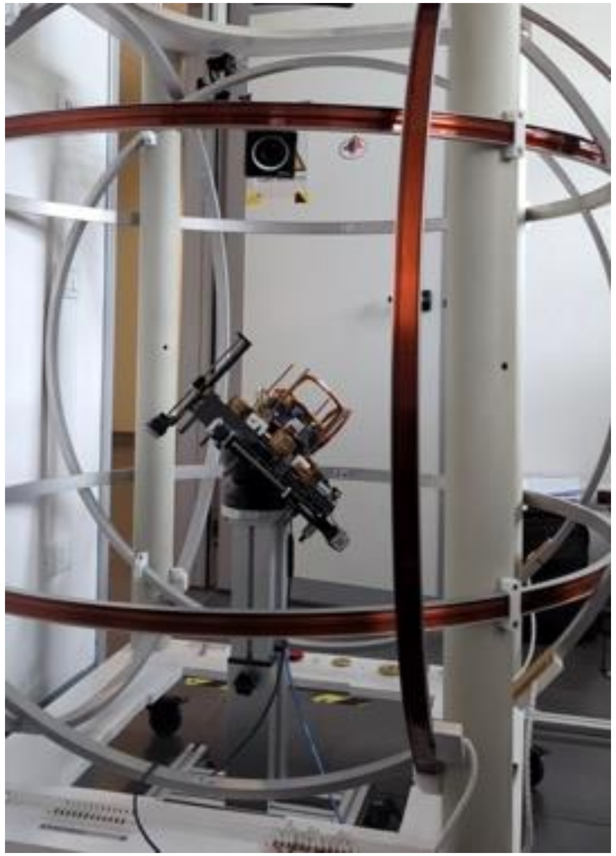
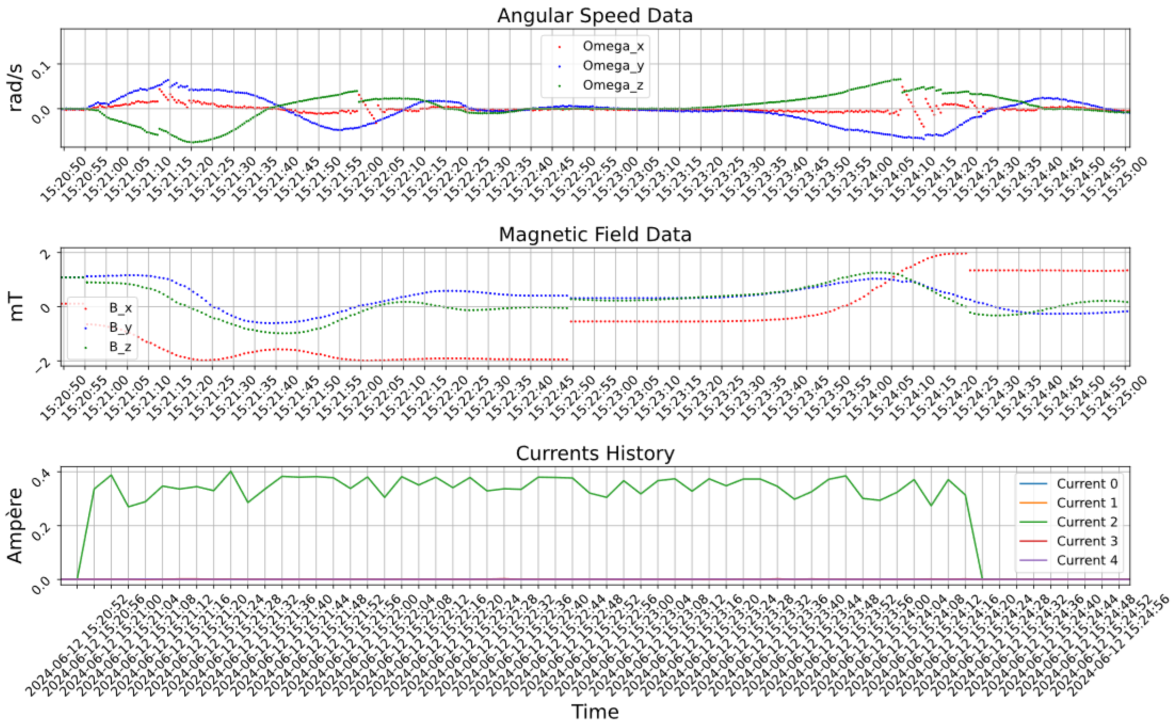
Integration and test campaign





Platform integration and mass balancing

Actuation test

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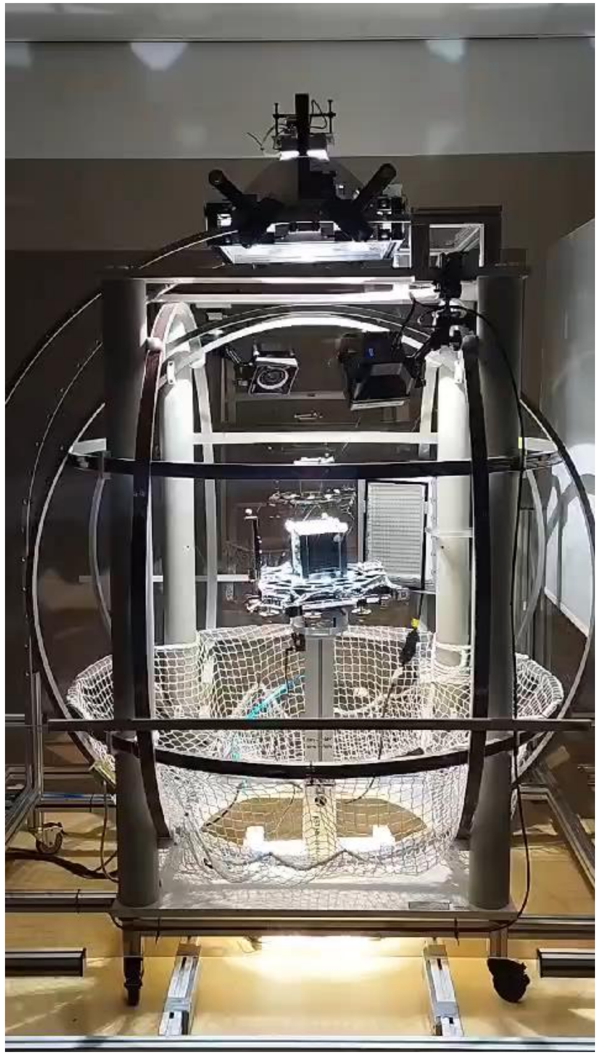
Concluding

- Ground testing of ADCS subsystems for CubeSat is of paramount importance to prevent on-orbit failures

- Building a facility for dynamic ADC testing on ground under flight representative conditions is very challenging

- CubeDynA is a long-lasting project at UniBo's u3S lab, intended to be in continuous development, highly rewarding both from educational and research standpoints



- CubeDynA MKI was developed and installed at University of Bologna premises

- The MKII, developed jointly with Nautilus - Navigation in Space, has been recently commissioned in ESTEC

- Hopefully, this new facility will serve as a key tool to enhance the success rate of the next-generation ESA-led CubeSat missions

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Questions?

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