

NAUTILUS
NAVIGATION IN SPACE

UNFOLDING
THE **DEEP SPACE**
POTENTIAL

NanoDynA - 3DOF Testbed for CubeSats Attitude Determination and Control

Dario Modenini

Founder at Nautilus

Associate Professor

Department of Industrial Engineering – Università di Bologna

NAUTILUS HERITAGE

UNIVERSITÀ DI BOLOGNA



- Orbit determination and radio science experiments for interplanetary missions
- Radio science experiment requirements definition for future deep-space missions experiments (phase A)
- Engineering software development and support to radio science experiments (phases B/C/D).
- Radio science data pre-processing and calibrations.
- Optical navigation algorithms
- **Attitude Determination and Control**



CASSINI
(NASA-ESA-ASI)



JUICE
(ESA)



BEPI-COLOMBO
(ESA)



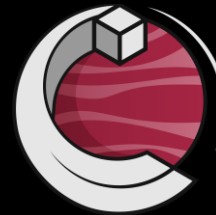
JUNO
(NASA)



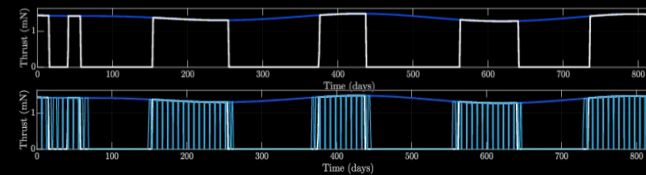
POLITECNICO DI MILANO



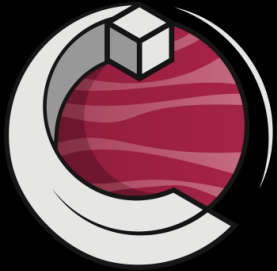
- Highly non-linear astrodynamics
 - Weak Stability Boundaries
- Autonomous interplanetary GNC
 - EXTREMA – ERC-funded project
- Optimal Control applications
 - Small Bodies Close Proximity Operations
 - Low-thrust Trajectory Design
- Autonomous Navigation
- Optical Navigation



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NanoDynA **CONSORTIUM**



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Nautilus Navigation in Space Srl – Prime Contractor
Alfredo Locarini – Project Manager
Dario Modenini – Technical Manager



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

INTERDEPARTMENTAL
CENTRE FOR INDUSTRIAL
AEROSPACE RESEARCH

Università di Bologna

Andrea Curatolo – System Engineer

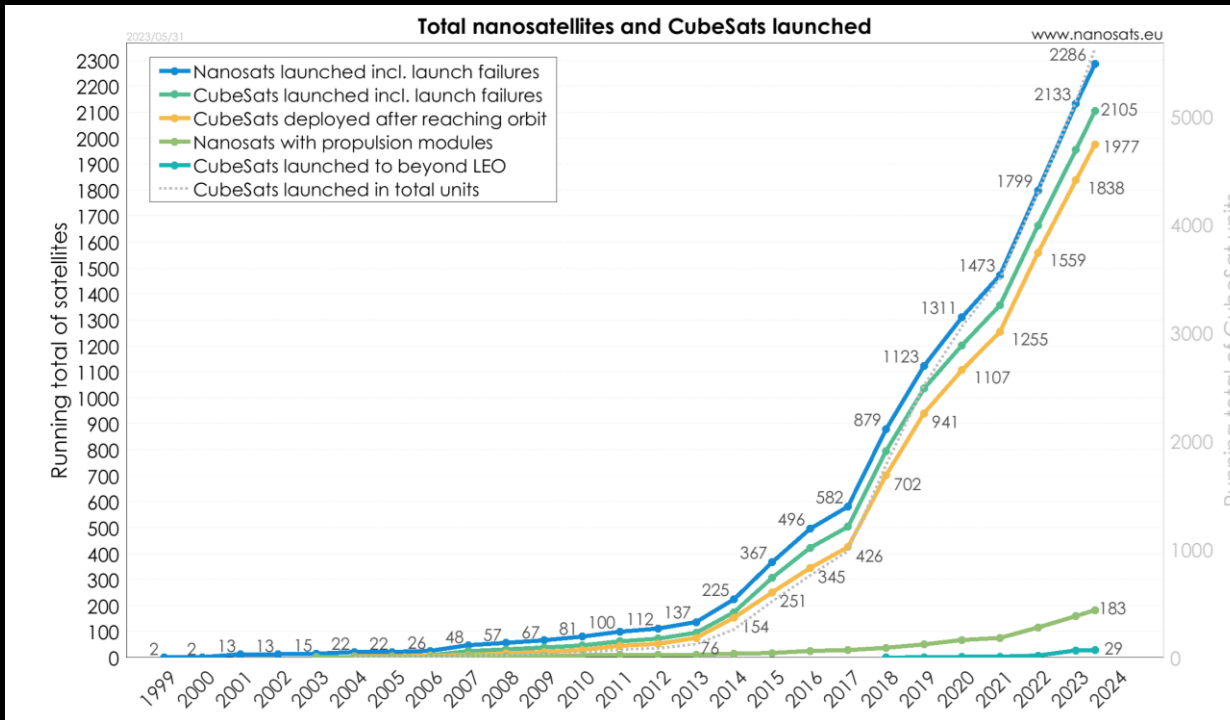
Daniele Pecorella, Giacomo Curzi, Alessandro Lotti, Project Engineers



European Space Agency – Funding Institute
Andrew Hyslop - Technical Officer

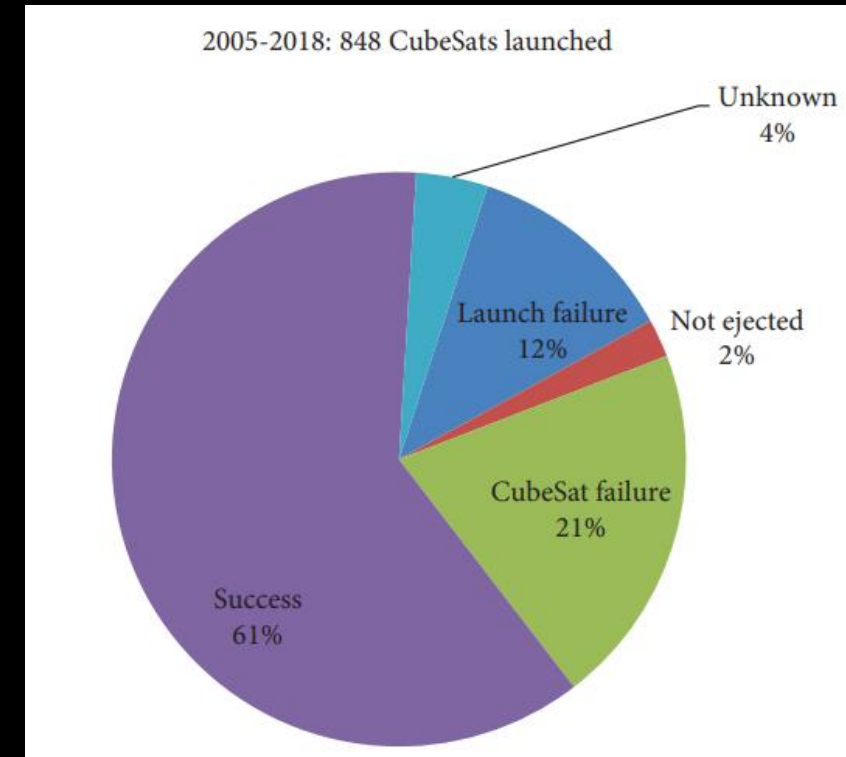
NanoDynA CONTEXT

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.

NanoDynA **CONTEXT**

“Flatsat” approach



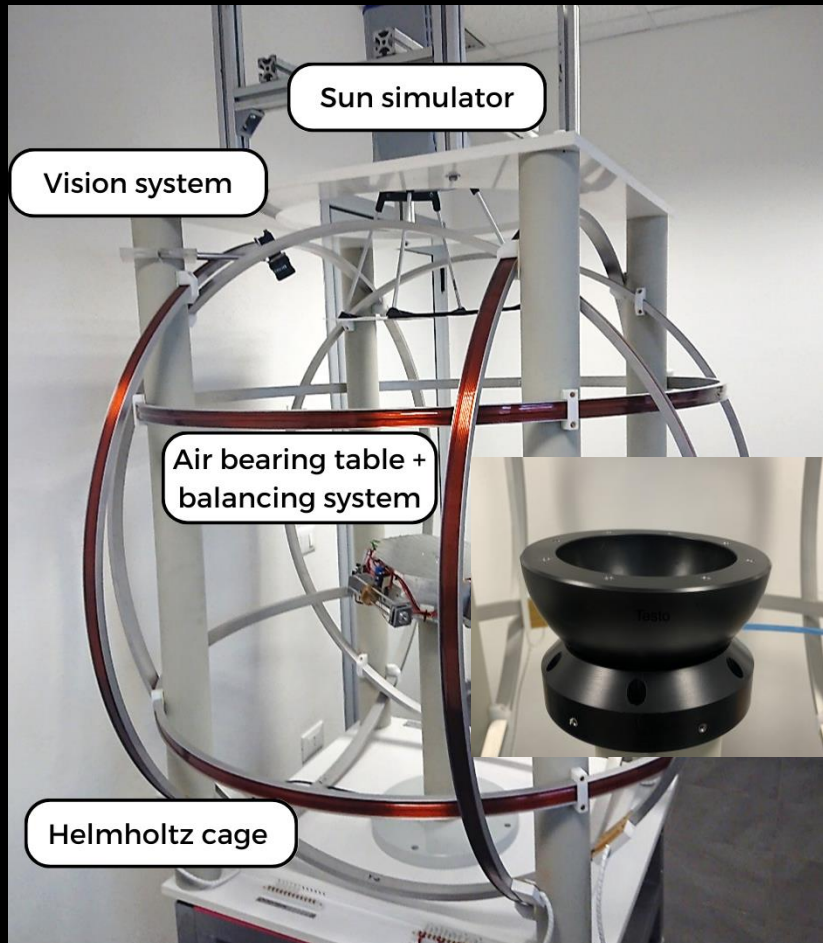
Credit: ESA

“Test-as-you-fly” approach



NanoDynA Heritage: MK1

NanoDynA - MK1



@ u3S Lab – Università di Bologna

- Developed at u3S Lab Università di Bologna since 2015
- 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 $\approx 0.3^\circ$ accuracy

NanoDynA **MK2**

- Suitable to test 1U, 3U, 6U and 12U CubeSats with sizes, mass, CoM positions specified by the CubeSat standard
- Standardized mechanical interfaces
- Pedestal with adjustable height for payloads in different orientations
- 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 and Earth's albedo (via Earth albedo lamp)
- Metal Halide Lamp for improved Sunlight spectral matching
- COTS ground-truth system for independent attitude estimation and optionally emulate star tracker – accuracy $\approx 0.1^\circ$
- Compatibility with ISO 8 class clean room/tent



NanoDynA **Magnetic Field Simulator**

- COTS Helmholtz cage: Ferronato® BH-1300-3-C from Serviciencia - Spain
- Three orthogonal coils (D \approx 1300 mm)
- Arbitrary magnetic field in the range ± 10 Gauss
- In-homogeneity below 1% in a sphere of 404 mm in diameter
- Nominal field-to-current ratio $50.5 \mu\text{T/A}$, $\pm 1\%$



NanoDynA Sun Simulator

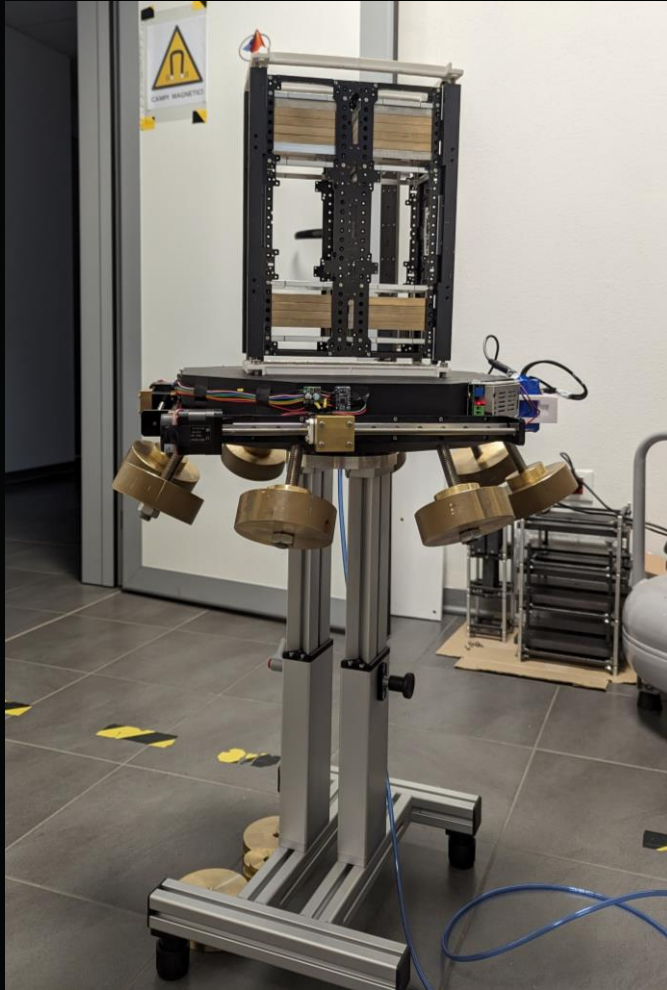


- Metal Halide Bulb for better sunlight spectral matching @ 5600 K
- Highly-accurate electroformed parabolic reflector for collimated light-beam
- Custom mechanical enclosure provides protection in case of catastrophic failure of the bulb
- Includes ten 12V DC fans for heat dissipation
- Frontal polycarbonete panel for UV radiation reduction

NanoDynA Tunable beta-angle simulation



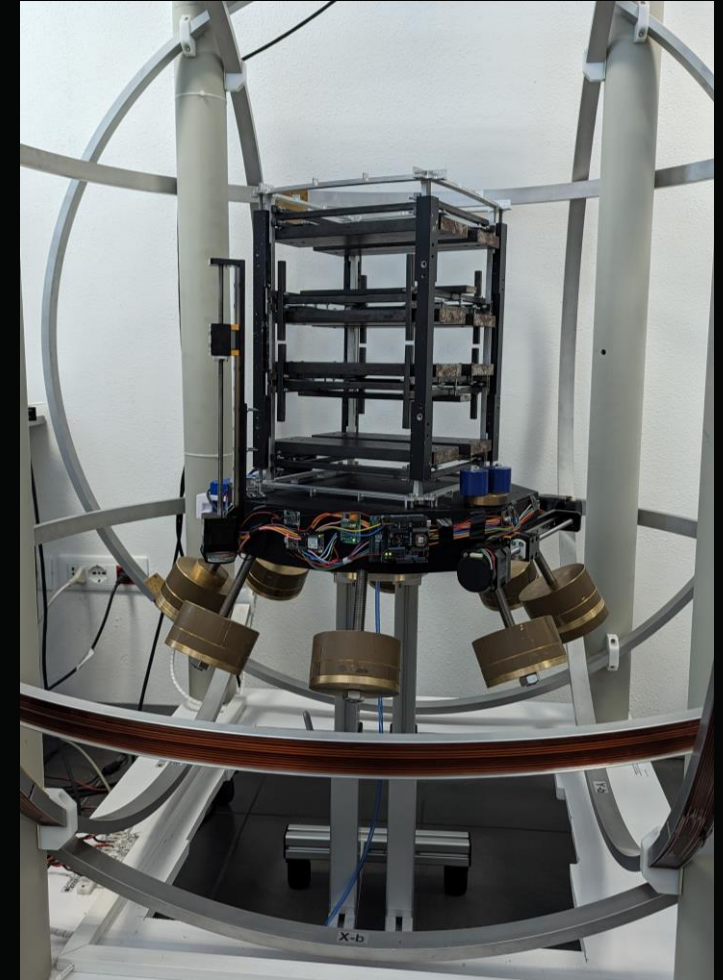
NanoDynA Standardized Mechanical Interfaces



6U CubeSat Mock-up Mounting
(6U Model courtesy of NPC – SpaceMind)

Mechanical fixtures act solely on
the CubeSat rail profiles interfacing
with the deployer

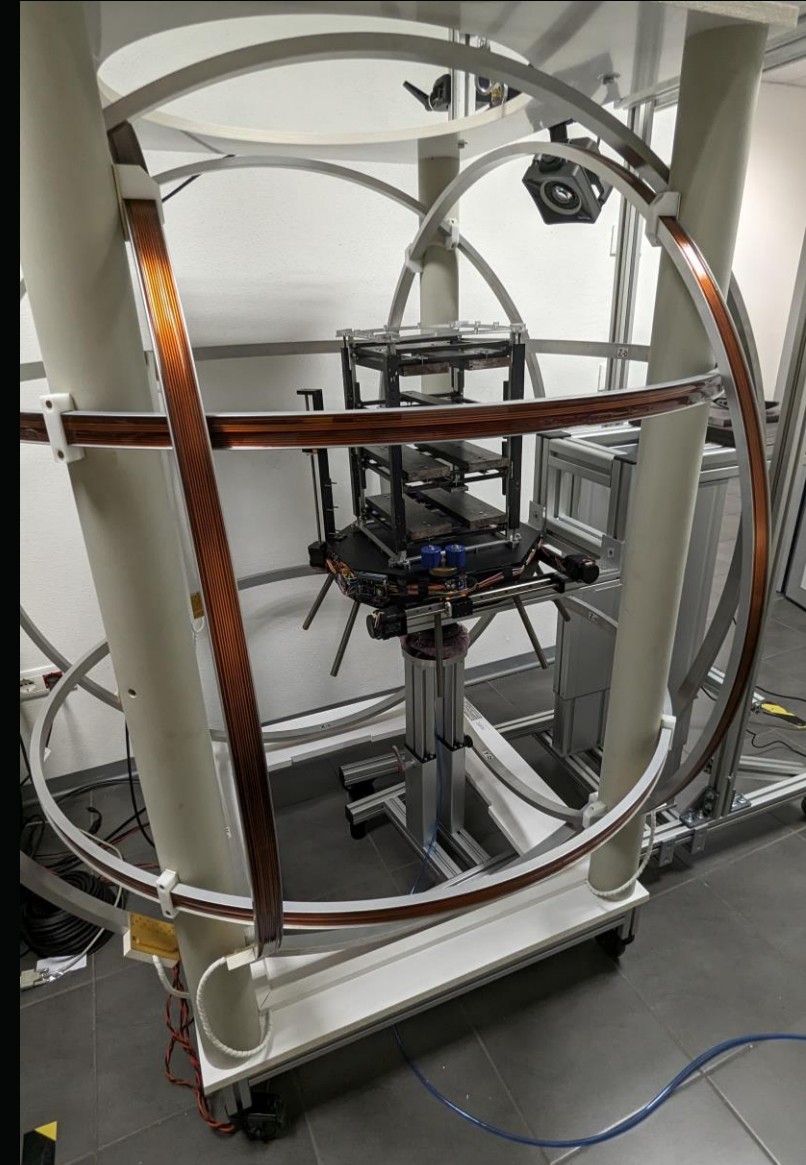
No other contact points to avoid
damages



12U CubeSat Mock-up Mounting

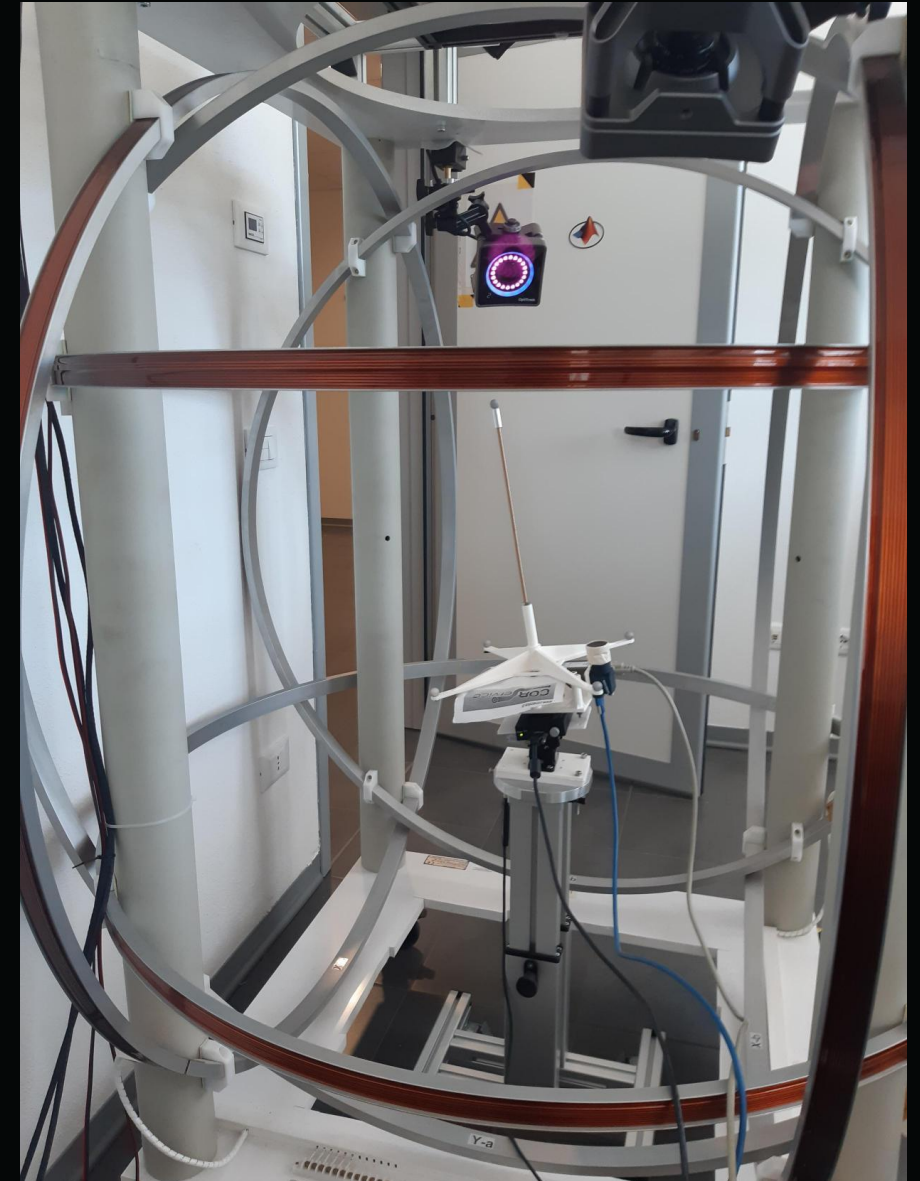
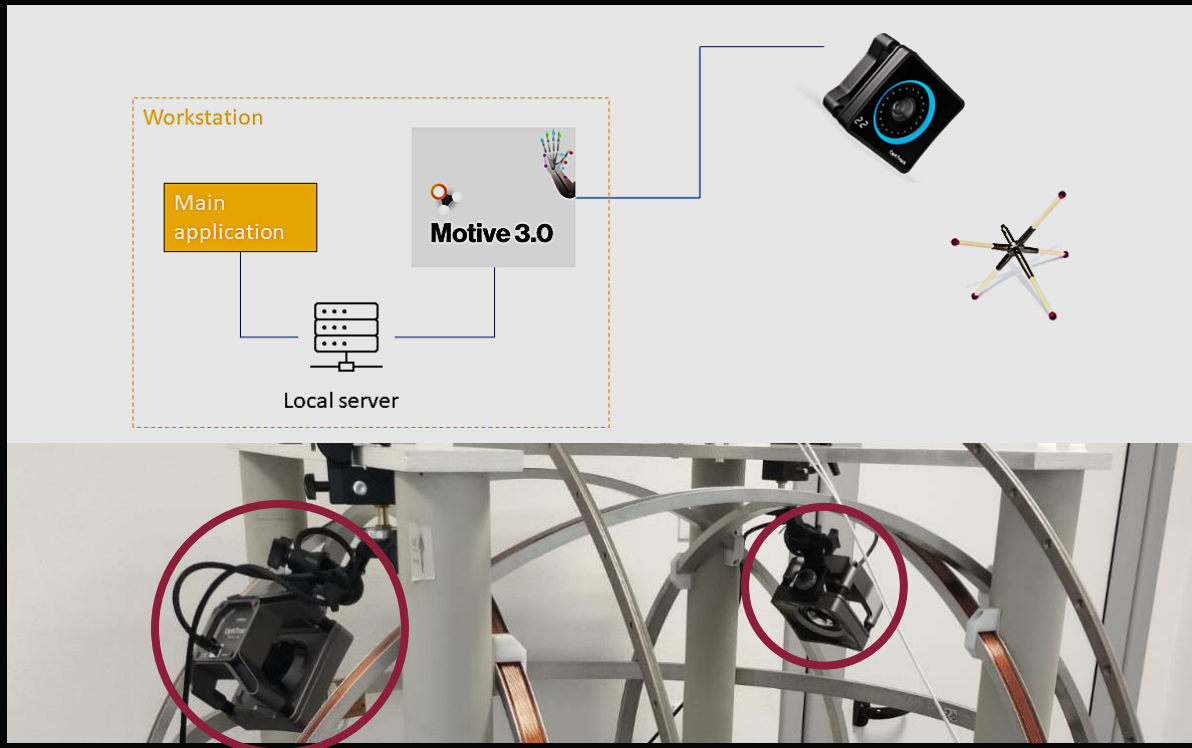
NanoDynA Mechanical Ground Support Equipment

- Lifter with custom design for positioning 6U and 12U CubeSats within the facility
- Electrically actuated
- Sized to fit within the cage with any orientation of the CubeSat under test
- Cleanroom compatible



NanoDynA Ground Truth Vision System

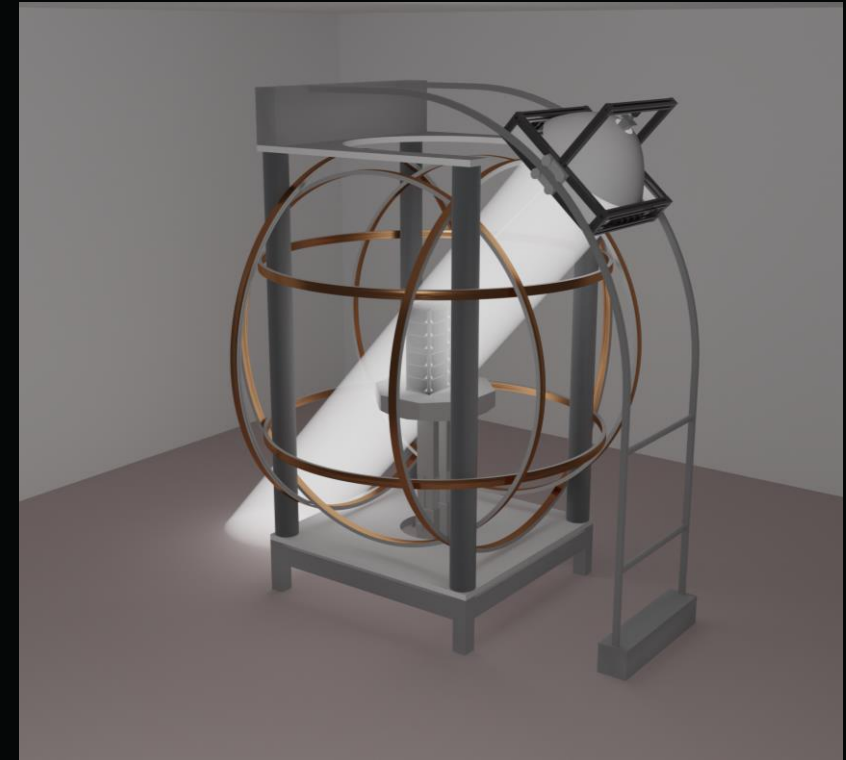
- COTS from Optitrack Inc
- High-speed MoCap stereo cameras 2Mpx
- Camera tracks reflective markers
- Pose solution at 200Hz



NanoDynA **Next Steps**

Facility
development
ends in July 2024

Delivery and
commissioning to
ESTEC in
September 2024



Planned an
upgrade to handle
16U CubeSats in
Q4 2024

NanoDynA **Conclusions**

- **NanoDynA MK2** is a brand-new facility that implements a “test-as-you-fly” verification approach for the **ADCS of CubeSats**
- Developed by **Nautilus – Navigation in Space + Università di Bologna** and funded by **ESA**, its first prototype will be shipped, installed, and commissioned in **ESTEC**
- The facility is capable of hosting full CubeSat platforms from 1U to 12U in any orientation
- If replicated (and further improved) in Italy, it could serve the ongoing national CubeSats missions, such as those of the **Alcor program**, as an effective tool for **reducing in-flight anomalies** thereby contributing to the missions' success



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