NAUTILUS
NAVIGATION IN SPACE

UNFOLDING
THE DEEP SPACE
POTENTIAL

Lunar and Deep-Space CubeSat Navigation Solutions

Alessio Quinci

Flight Dynamics Engineer at Nautilus

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NAUTILUS

*Becoming the leading provider of **Flight Dynamics** services for **lunar** and **deep space** missions, enabling world's transition from terrestrial to interplanetary markets.*

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NAUTILUS HERITAGE

SPIN
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

spin off®
POLITECNICO DI MILANO

UNIVERSITÀ DI BOLOGNA

Radio Science and Planetary Exploration Laboratory

- **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.

CASSINI (NASA-ESA-ASI)

JUICE (ESA)

BEPI-COLOMBO (ESA)

JUNO (NASA)

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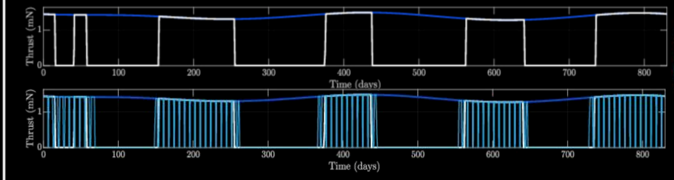
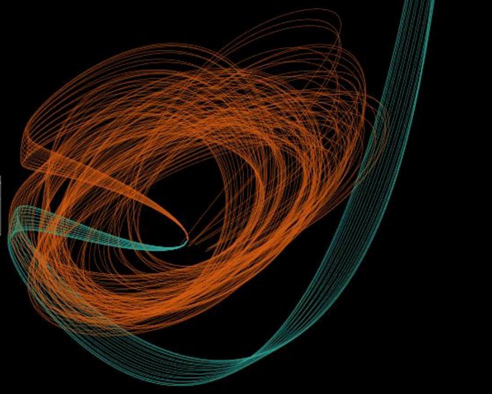
POLITECNICO DI MILANO

DART Group

- 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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NAUTILUS **EXPERTISE**

Flight Dynamics Experts

- FD software development
- Mission analysis

Precise Orbit Determination
- LEO/GEO
- Deep Space

- Maneuver optimization
- Conjunction Assessment
- Collision Avoidance

Real-time navigation operations
- Prime / Shadow

- Innovative FD solutions
- FD as a service
- Developing on-board solutions

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NEMO SOFTWARE

nemo

Navigation and trajectory Engineering software for Missions in Outer space

Flight Dynamics Software Suite to enable **easy** and **cost-effective** Navigation and Guidance of Lunar and Deep-Space Spacecraft

- Real-time radiometric data processing
- Smart scheduling
- Task Automation
- Interactive monitoring cockpit
- Modularity & Customization

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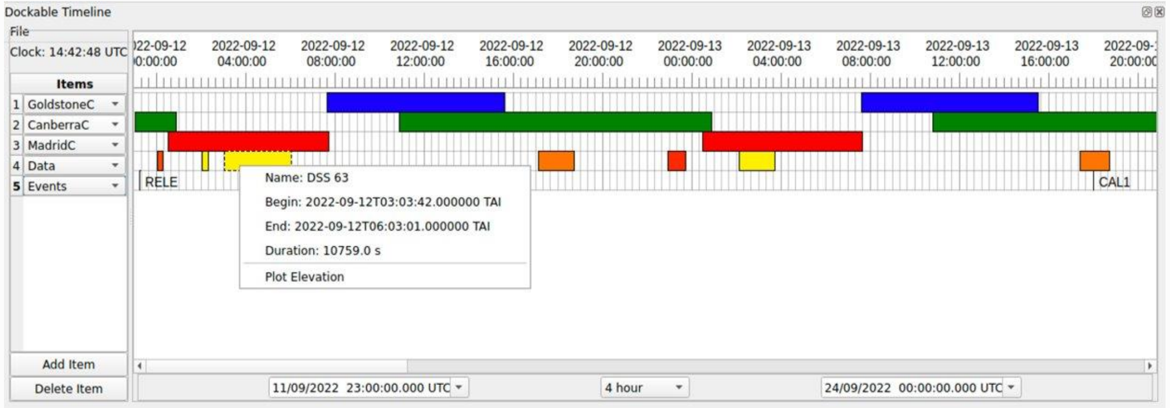
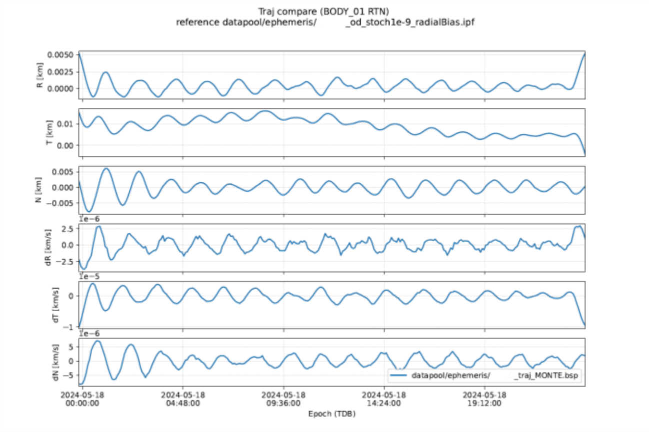
NEMO SOFTWARE

esa BUSINESS INCUBATION CENTRE Milan

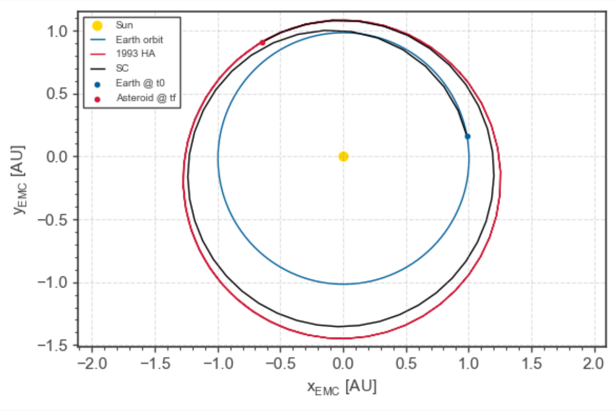
Timeline



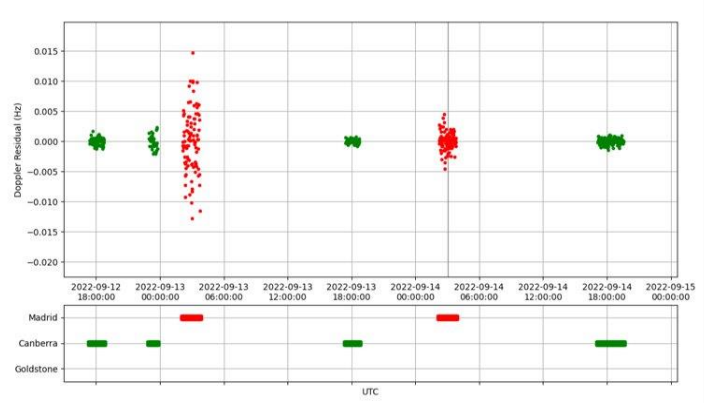
Orbit Analysis



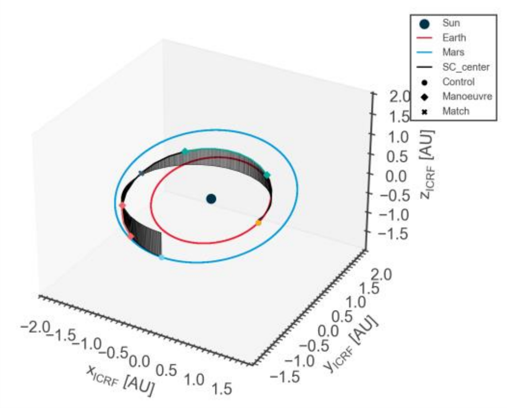
Mission Analysis



Navigation



Guidance



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NAUTILUS **SERVICES**

Deep Space Navigation
Detailed Overview

- OD reports and maneuver decision meetings
- Trajectory reconstruction and comparison
- Covariance comparison
- Radiometric data Passthrough and Analysis
- Maneuver computation and reconstruction
- Trajectory optimization

Different levels of support:
Real-time, Off-line, on demand for critical phases

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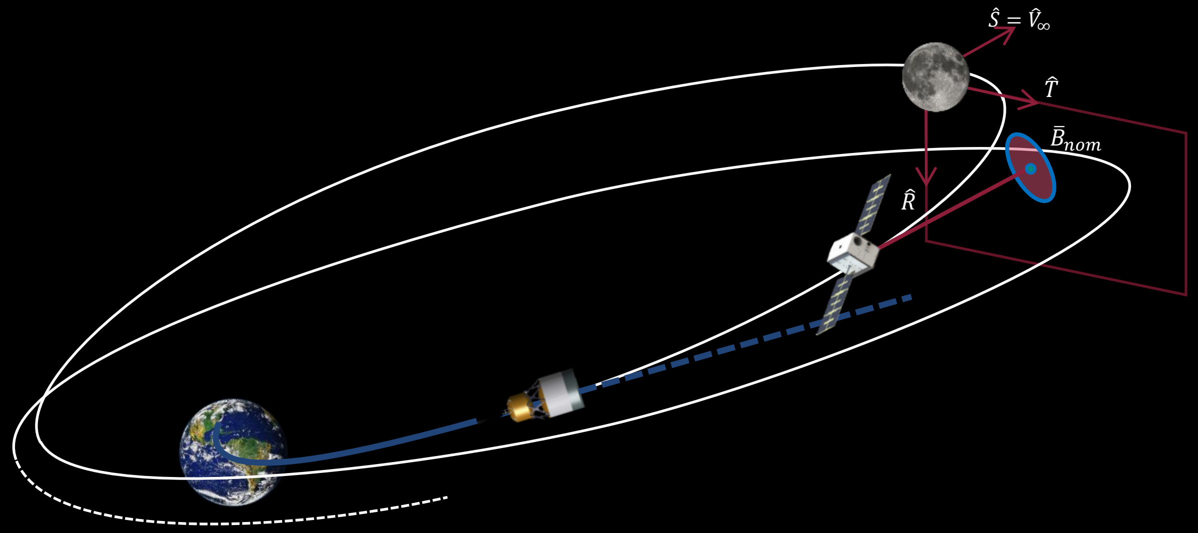
MOON MISSIONS

Challenges

- Many satellites release condition (SLS)
- Limited communication windows
- Precise Orbit Determination to satisfy ground stations pointing requirements and to reduce orbit dispersion when targeting the Moon (impact avoidance, planetary protection)



Navigation solution

Earth-based radiometric navigation (Range, Doppler) → 10 m level accuracy

✅ PROS

- Doppler included in 2-way communications
- Range can be included in communications with a small datarate loss

❌ CONS:

- No info about the relative position with respect to the target (e.g. Moon)
- Requires GS coverage and man-hours

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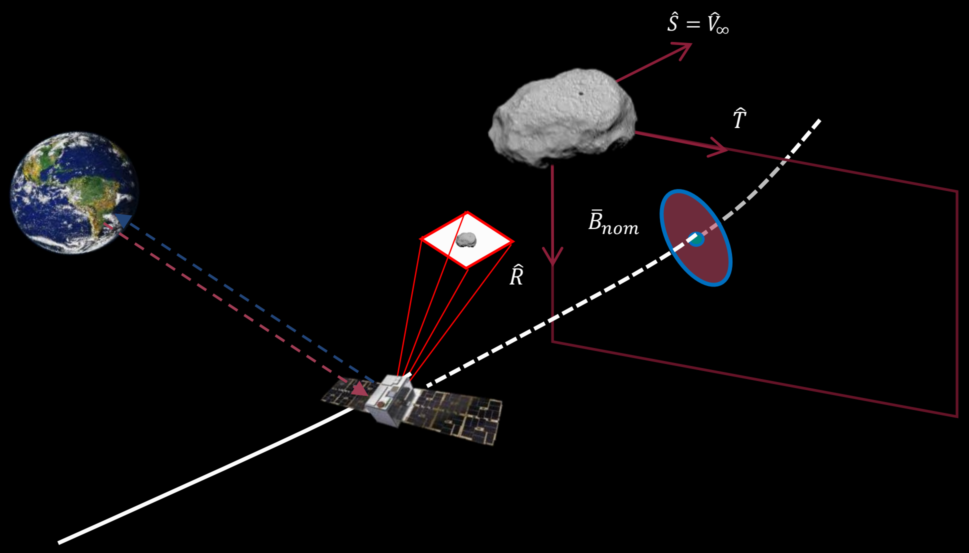
RENDEZ-VOUS MISSIONS

Challenges

- Proximity and landing phases require **accurate** knowledge of SC-target **relative state**
- Uncertainty on target asteroid ephemeris

Solutions

- **Optical navigation** for close encounter as additional source of information
- **LIDAR** for relative velocity and positioning during landing phase
- ISL if available (multiple spacecraft)
- Radio science experiments to improve ephemeris accuracy of the target asteroid



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LUMIO MISSION

esa POLITECNICO MILANO 1863

Consortium

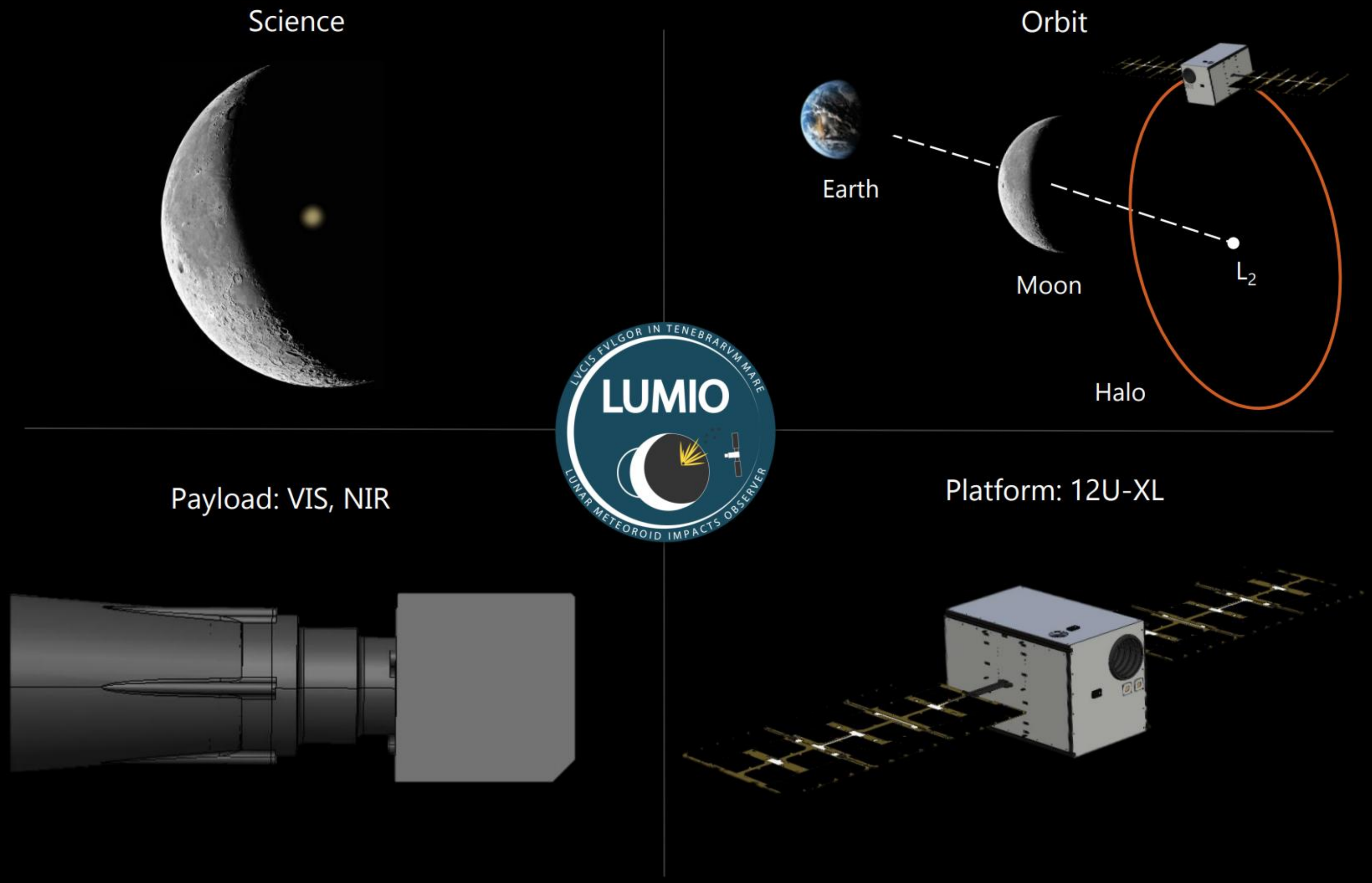
Polimi, Argotec, Leonardo, IMT, S&T, Nautilus

Highlights

- 12U XL CubeSat
- WSB transfer to Earth-Moon L2 Halo Orbit

Activities

- Phases B-C: Ground Segment and Operations Design
- Next phases: Operational Orbit Determination & Orbit Control



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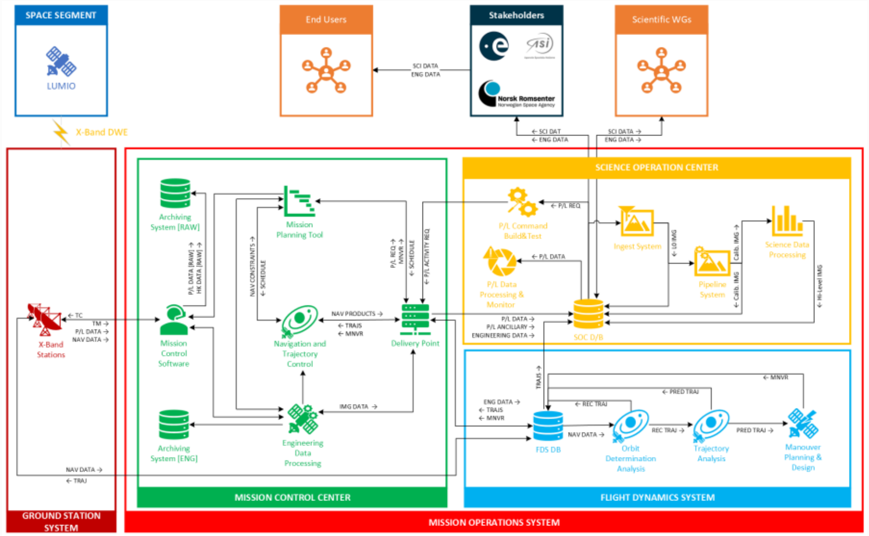
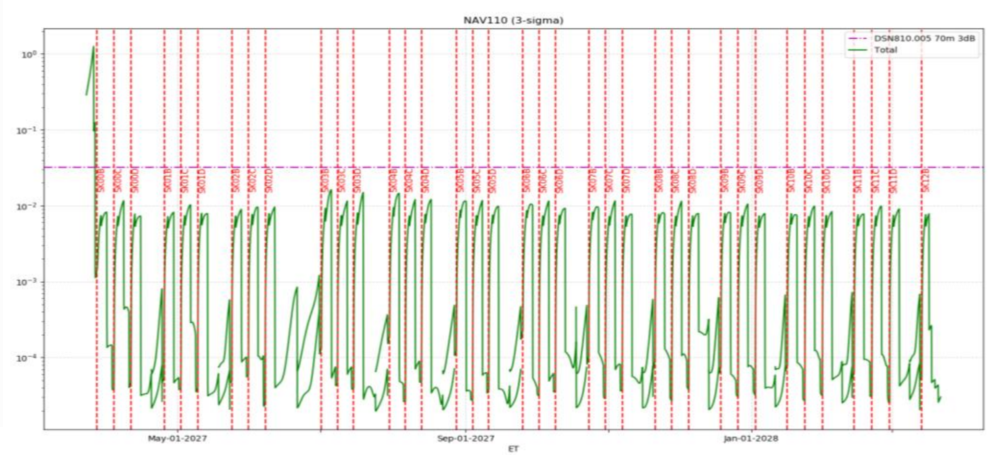
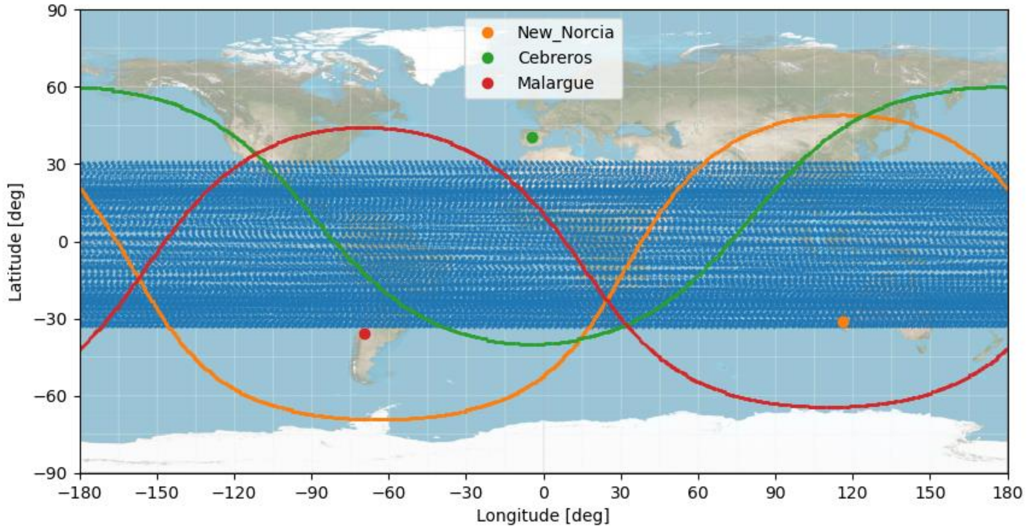
LUMIO MISSION

CONTRIBUTION

- Ground segment achitecture definition
- Coverage analysis and tracking windows compatibility
- Station keeping strategy validation
- Prelimary tracking schedule and navigation analysis







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NAUTILUS SERVICES

LEO Precise Orbit Determination and Flight Dynamics OPS

Detailed Overview

- GPS- and radiometric-based orbit determination
- Trajectory reconstruction and comparison
- Collision Assessment and Avoidance Manoeuver design
- LEOP Preliminary orbit determination
- Maneuver optimization, reconstruction and calibration
- Reference orbit acquisition strategy definition and implementation

Different levels of support:
Real-time, Off-line, on demand for critical phases

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NEMO SOFTWARE

CASE STUDY

GOAL

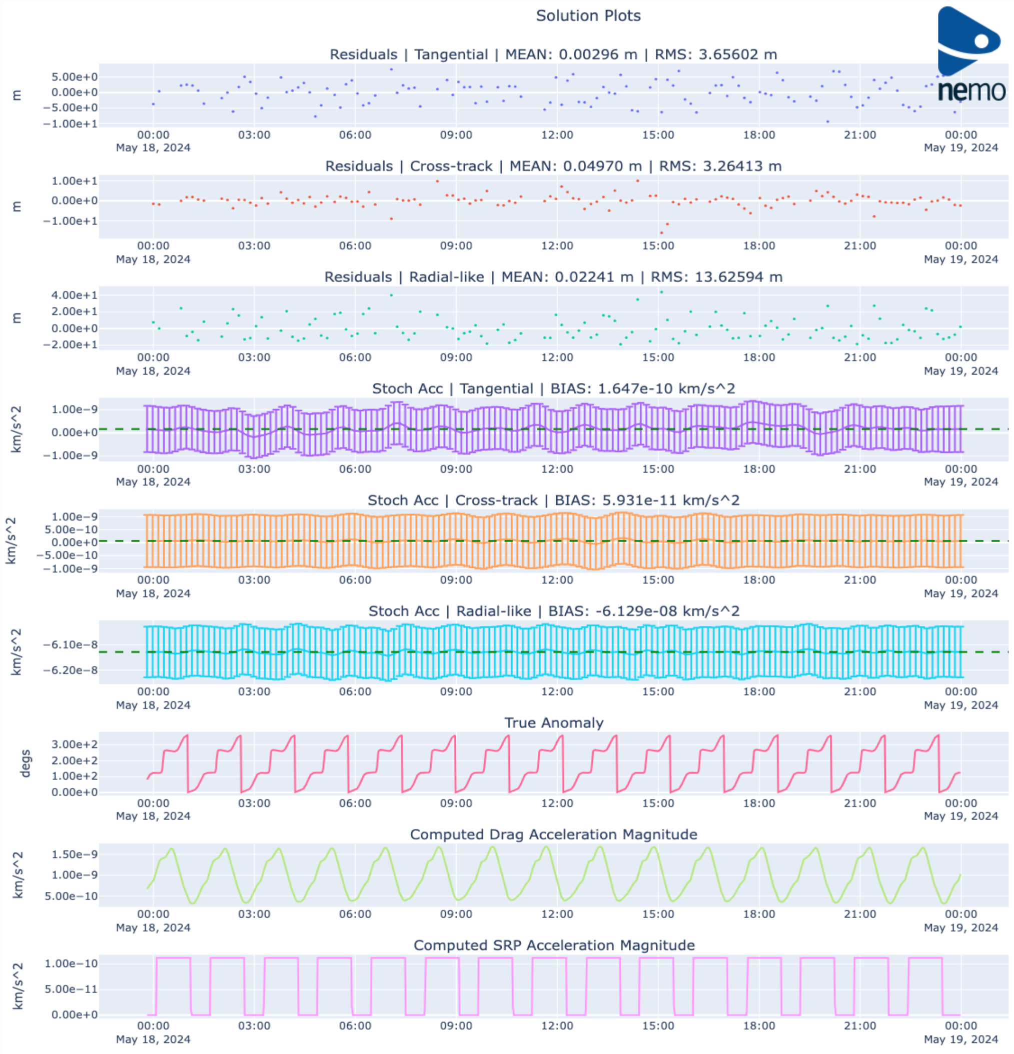
To perform a POD of a 6U CubeSat, placed on a 550-600 km Sun-Synchronous orbit, with in-house NEMO Python toolkit based on ESA GODOT

PROCEDURES

- Satellite dynamical model setup
- GPS data pre-processing
- Satellite a-priori state @ T0 obtained from TLE
- Fitting performed with SRI least square filter
  Estimated parameters are satellite initial state @ T0, drag and reflection coefficients, stochastic accelerations
- Post-process (orbit files and plots generation)

RESULTS

- Post-fit residuals and state covariance are sufficiently small to enable accurate orbit reconstruction and satisfy antenna pointing requirements
    - 10x improvement wrt previous approach



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NAUTILUS **TEAM**

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