Onboard Autonomy for SmallSats with autoNGC

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What is autoNGC?

An ***onboard*** *software application suite built on the core Flight System (cFS) and flight hardware that performs* ***real-time autonomous*** *spacecraft* ***navigation, guidance, and control*** *(NGC)*

Where am I?

How do I get to where I want to go?

How do I stay on the planned path?

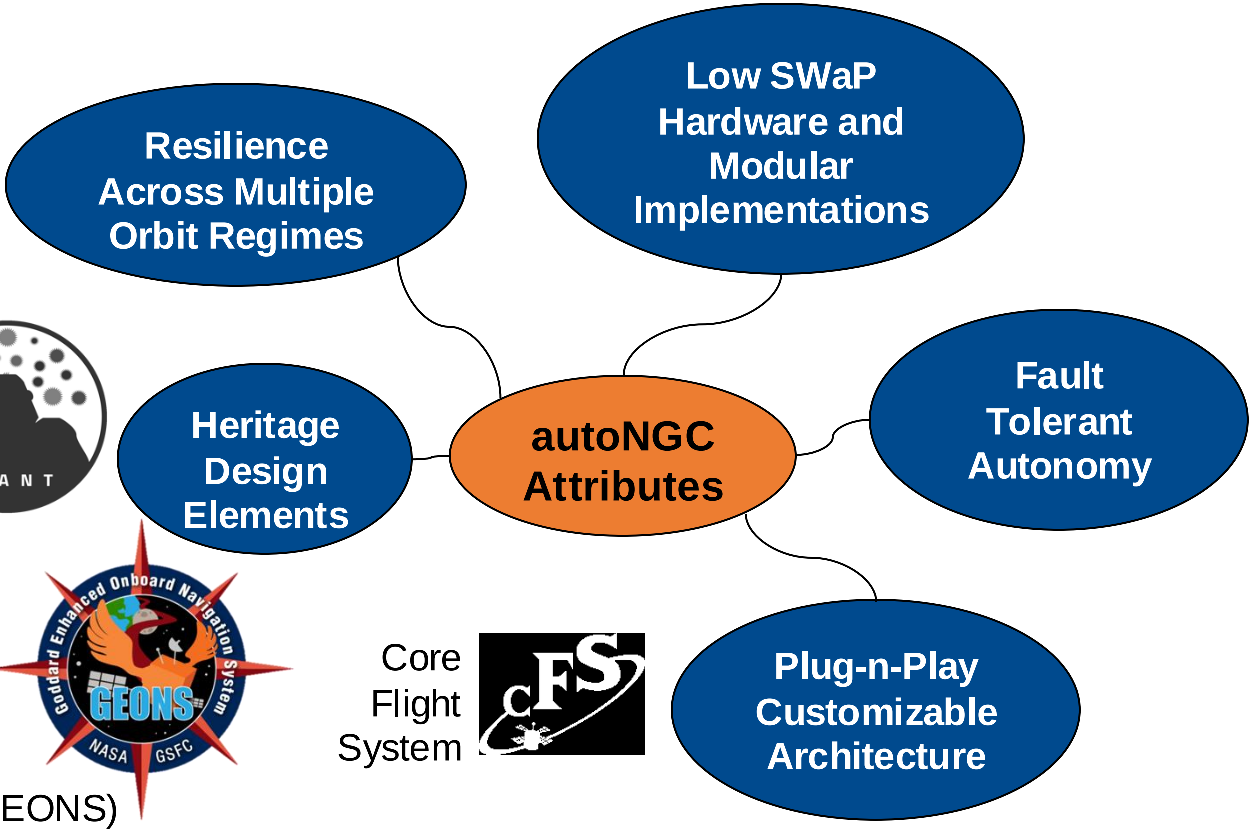
Why autoNGC?

- Reduces reliance on over-subscribed ground assets and costly ground operations
- Enables new mission capabilities
  - *Low latency mission operations*
  - *Complex missions at far distances, e.g., Touch-and-Go (TAG) Guidance*
  - *In-situ planning and execution*
  - *Distributed Systems Missions (DSMs)*
  - *Dynamic replanning/reallocation of orbital assets*

Goddard Image Analysis and Navigation Tool (GIANT)

Goddard Enhanced Onboard Navigation System (GEONS)

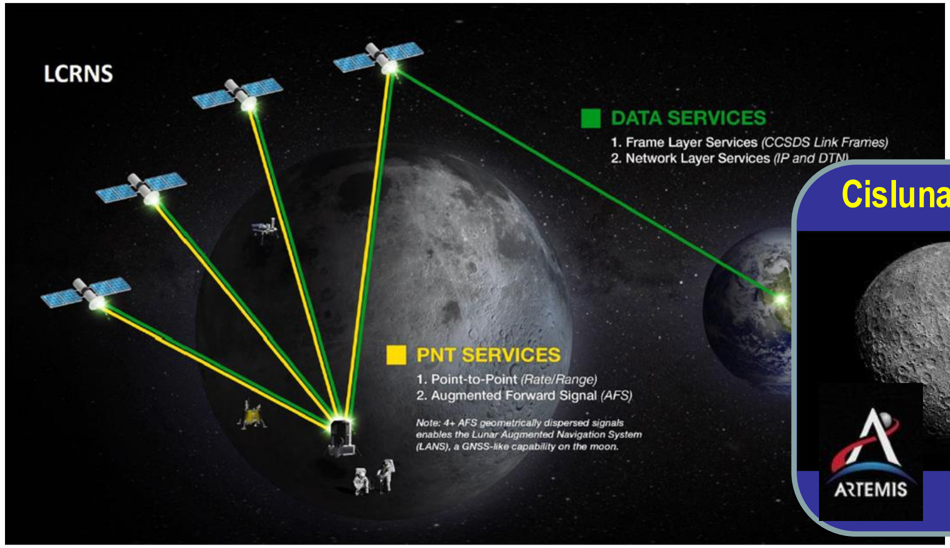
Core Flight System



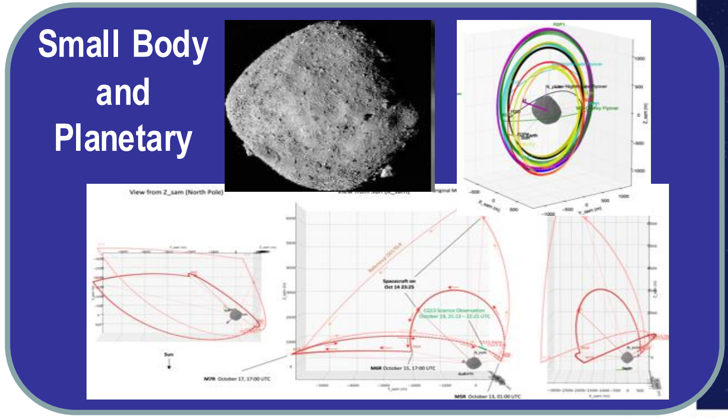
autoNGC Capabilities Support Multiple Use Cases (1/2)

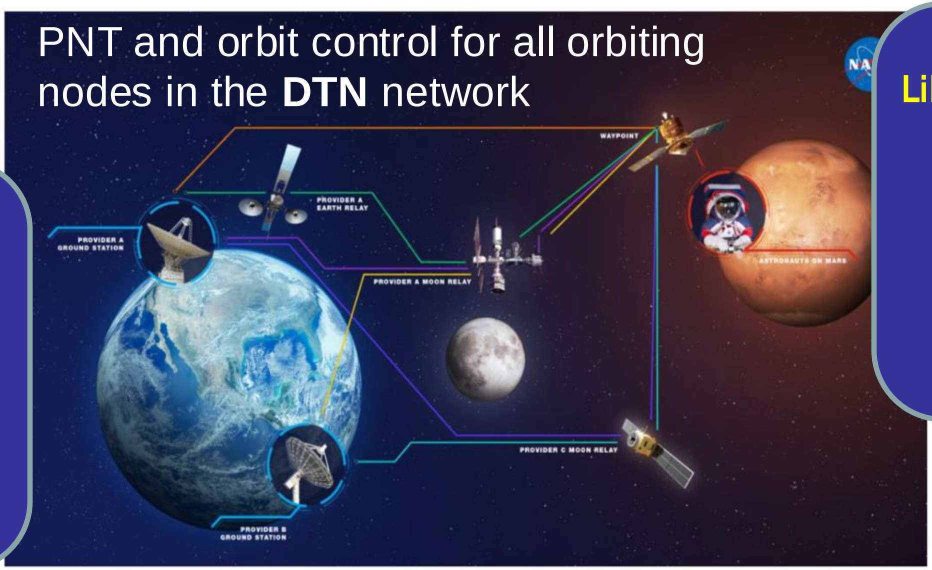
Cislunar PNT capability

- Lunar Communications Relay and Navigation Systems (LCRNS)
  - Measurement capabilities include:
    - GPS pseudo-range & time-differenced carrier phase
    - 1-way Direct to Earth (DTE) pseudo-range and Doppler
    - 2-way DTE range and Doppler
    - Terrain Relative Navigation (TRN) (surface images)
    - Limb-based optical navigation
    - Accelerometer processing

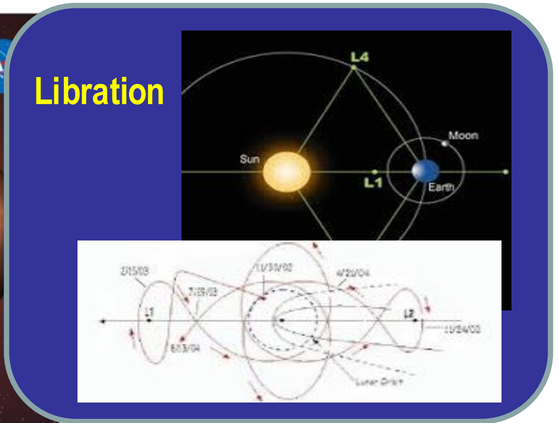


Touch-and-Go Guidance System (TGS)

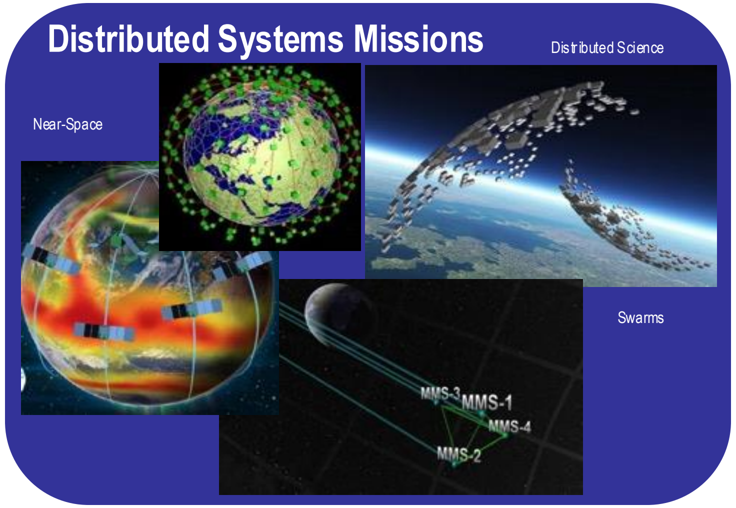




Delay/Disruption Tolerant Networking (DTN) enables the use of multiple paths and providers to efficiently deliver data

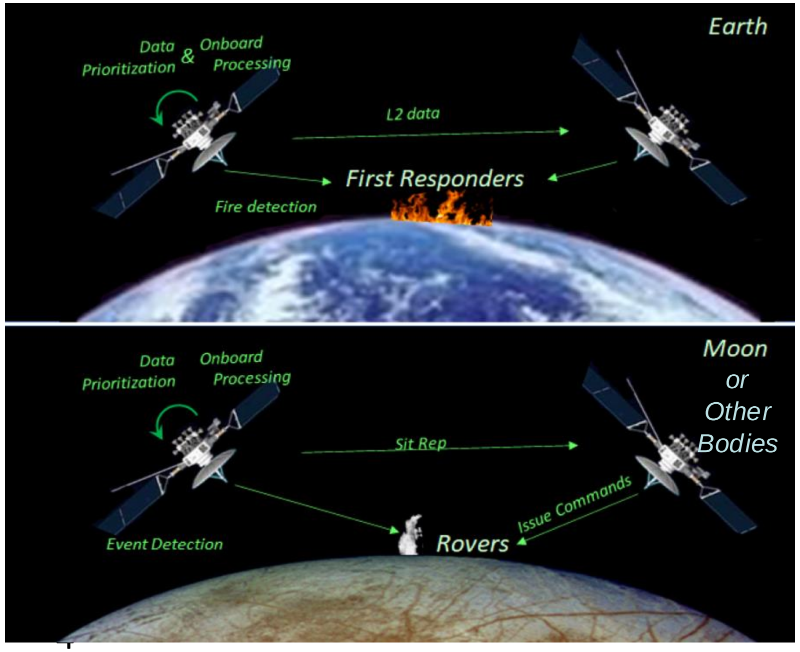


autoNGC Capabilities Support Multiple Use Cases

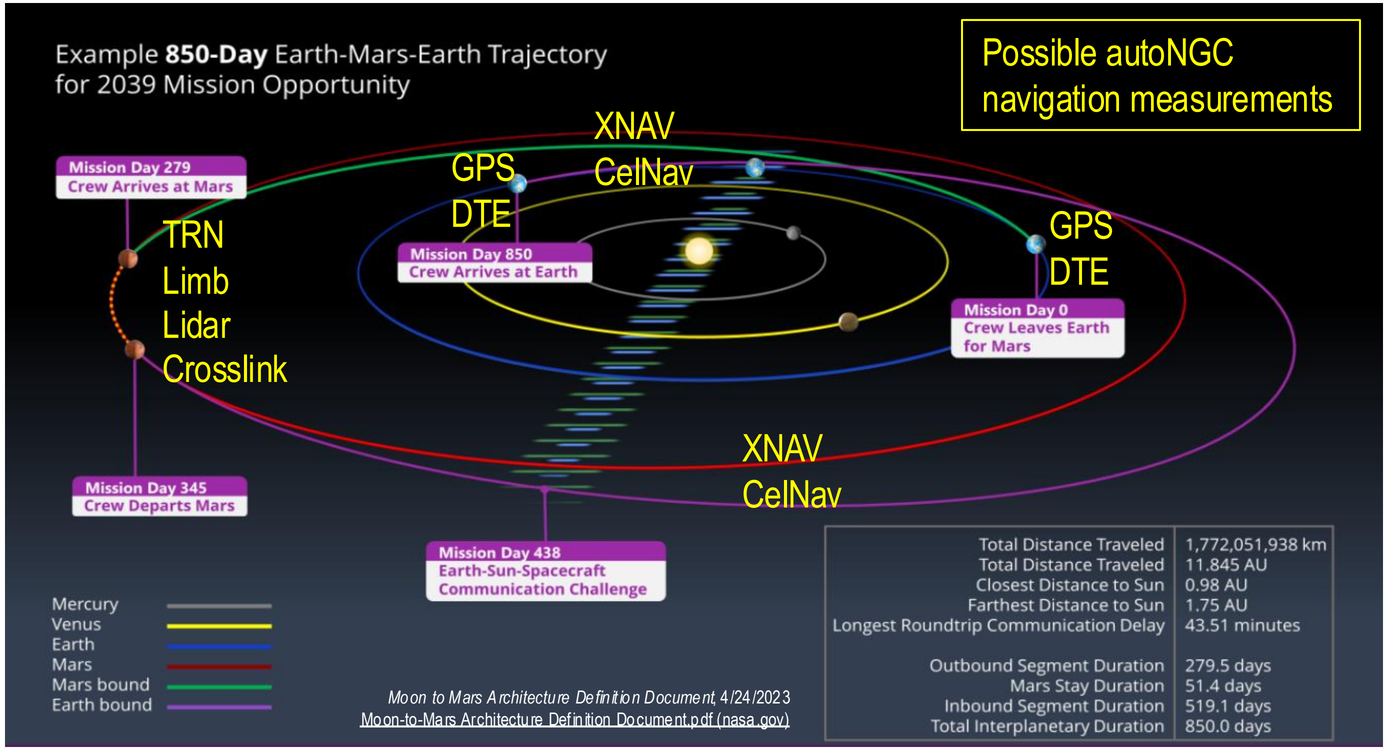


autoNGC extensions applicable to Moon to Mars effort:

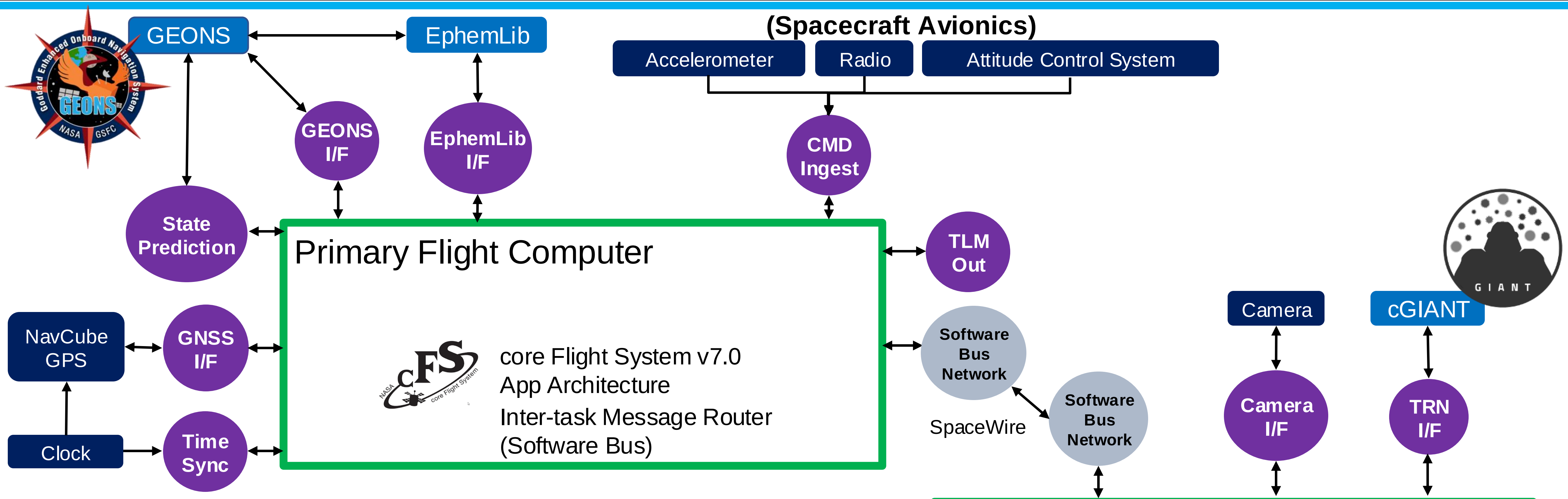
- LiDAR altimetry
- X-ray pulsar navigation (XNAV)
- Celestial navigation (CelNav) (imaging planets, asteroids)
- Cross-link range and Doppler (multi-system navigation)
- Trajectory correction
- Event driven planning/scheduling (coordinated GN&C and payload)

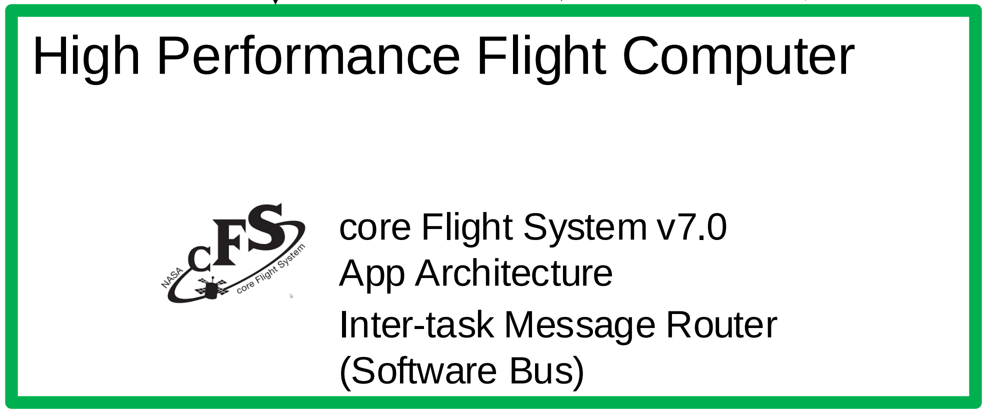


Autonomy during multiple phases of a Mars mission



Flight Software
Target Implementation for Lunar Navigation





Navigation Sources

- Weak-Signal GPS
- Terrain-Relative Nav (TRN)
- 1-Way Forward Direct to Earth (DTE)
- 2-Way DTE
- Accelerometer
- Rubidium Clock

Core autoNGC cFS apps. Not all apps are shown

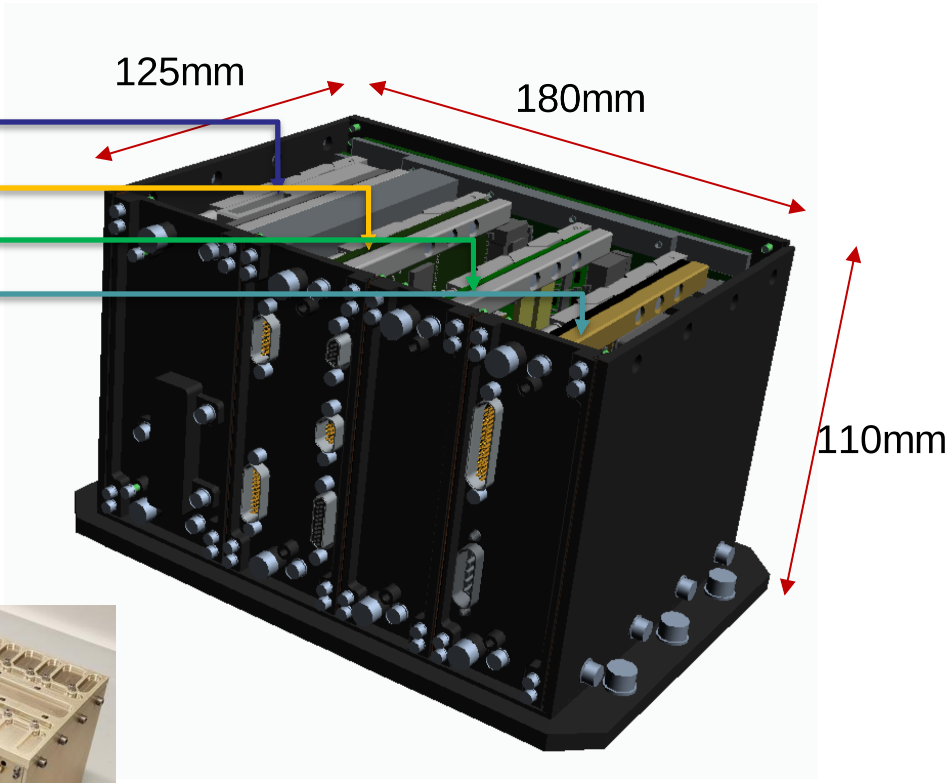
Hardware: Target Design for Lunar Navigation

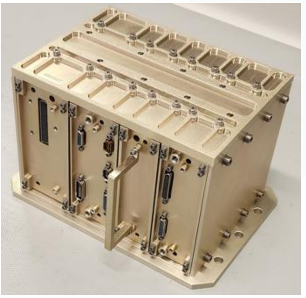
CubeSat Card Specification (CS)^2

Box Components:

- **Two Processor Card Implementation**
  - Primary Processor Card
    - *Xilinx Kintex UltraScale with RISC-V Software Processor*
    - *2GB DDR3 SDRAM (x72 wide for ECC) / 2x 16GB NAND Flash*
  - Secondary Processor Card
    - *Xilinx Zynq with Dual ARM Cortex-A9*
    - *1GB DDR / 4GB NAND Flash*
- **Low Voltage Power Card (LVPC)**
  - 28V Input, 6x internal switched services of 3.3V, 5.0V or 12V power rails, Voltage and Current Monitoring
- **Configurable IO Card**
  - 12 Buffered Differential Transmitters (LVDS or RS422)
  - 12 Buffered Differential Receivers (LVDS or RS422)
  - 16 Buffered Single Ended Lines
  - 32 Un-Buffered Signals – Routed as Differential Pairs
- **Backplane**
  - Power Distribution, 8-Channel Temperature Monitoring, and Point-to-point topology for high-speed data interfaces

Mass	< 2.5 kg
Power	10 W (Nominal), 15 W (Peak)



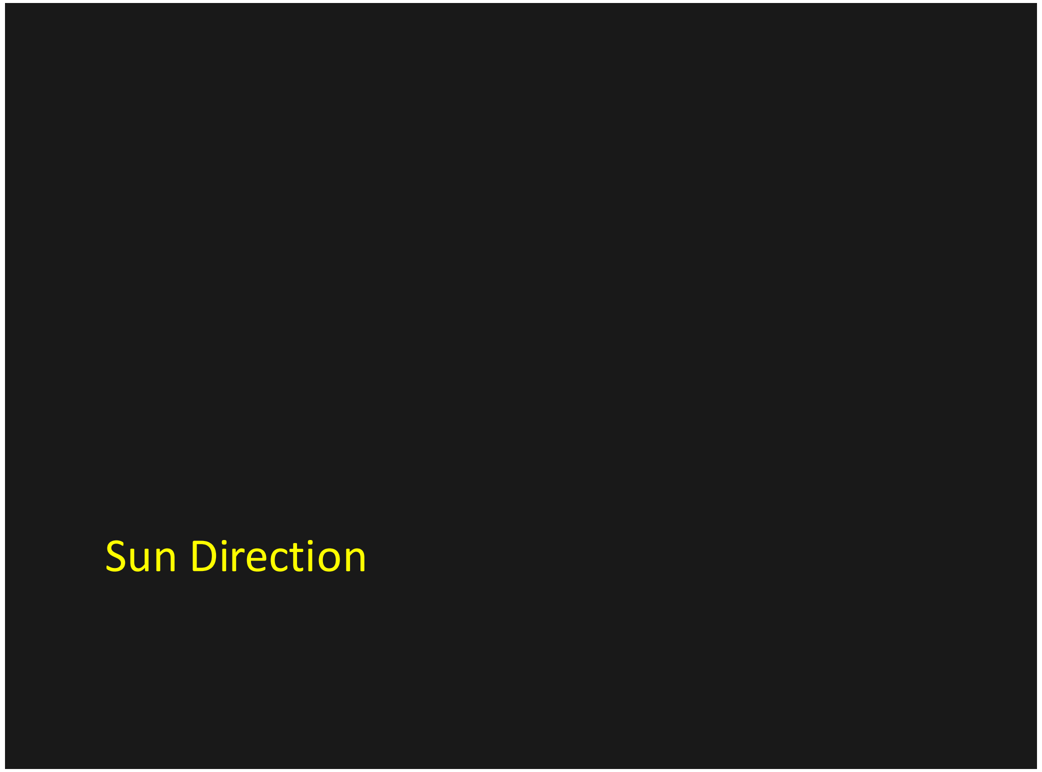


Lunar Orbit Navigation Scenario with GPS+TRN

12-hour elliptical frozen orbit

Semi-major axis: 6.14e6 m
Eccentricity: 0.5428
Inclination: 74.6 degrees

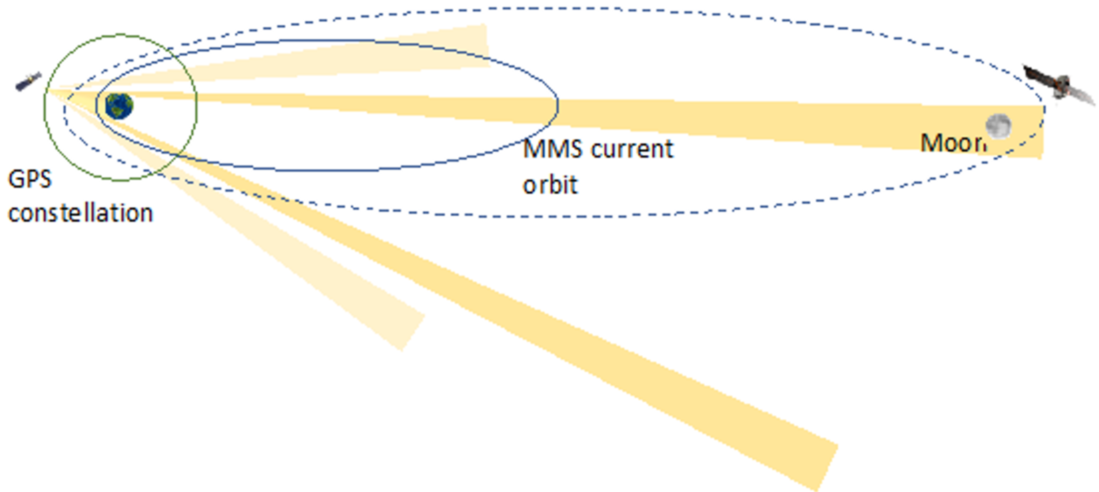
RAAN: 259 degrees
Argument of Periapsis: 77.7 degrees
True Anomaly: 178 degrees



NavCube3-mini (NC3m) GNSS Receiver

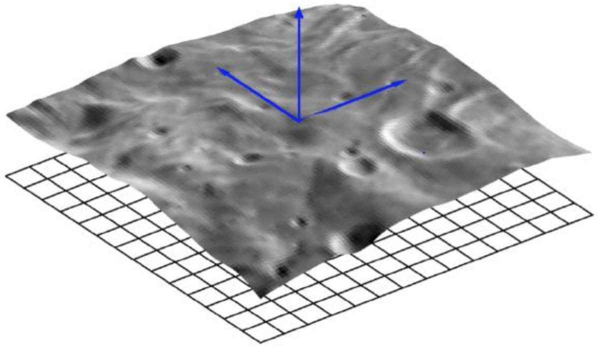
- Low-SWaP multi-GNSS receiver, suitable for use in cis-lunar/lunar space
- Combined fast and weak signal acquisition; builds on flight-proven Navigator GPS receiver software and firmware on the GSFC Magnetospheric Multiscale (MMS) Mission
- Includes integrated Goddard Enhanced Onboard Navigation System (GEONS) navigation filter

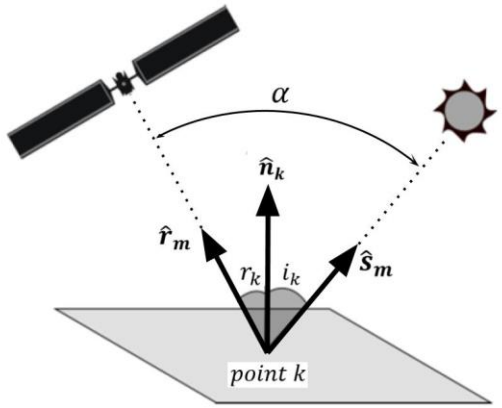
- **NC3m achieved Technology Readiness Level 6 in 2022**
- **Other Attributes:**
  - *On-orbit upgradable, FPGA-based radiation tolerant*
  - *GPS L1C/A and L2C capability*
  - *GPS L5 and Galileo E1 and E5a capabilities in development*
  - *Size: WxDxH: 5.0”x5.0”x4.0”*
  - *Mass: 1.5 kg*
  - *Power: <13 W*



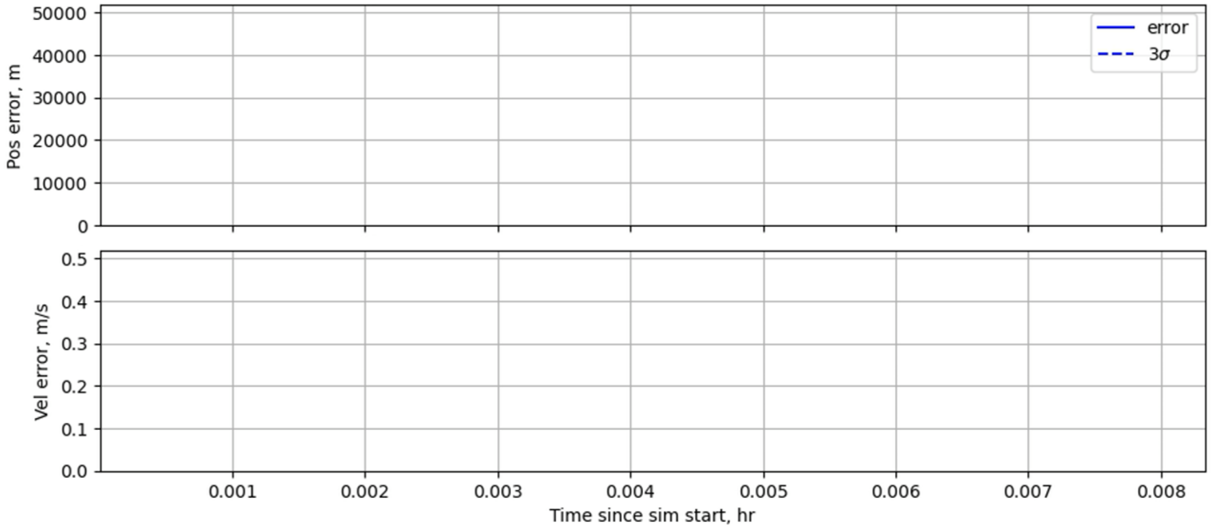
Terrain Relative Navigation (TRN) Uses Surface "Features" to Help Us Navigate

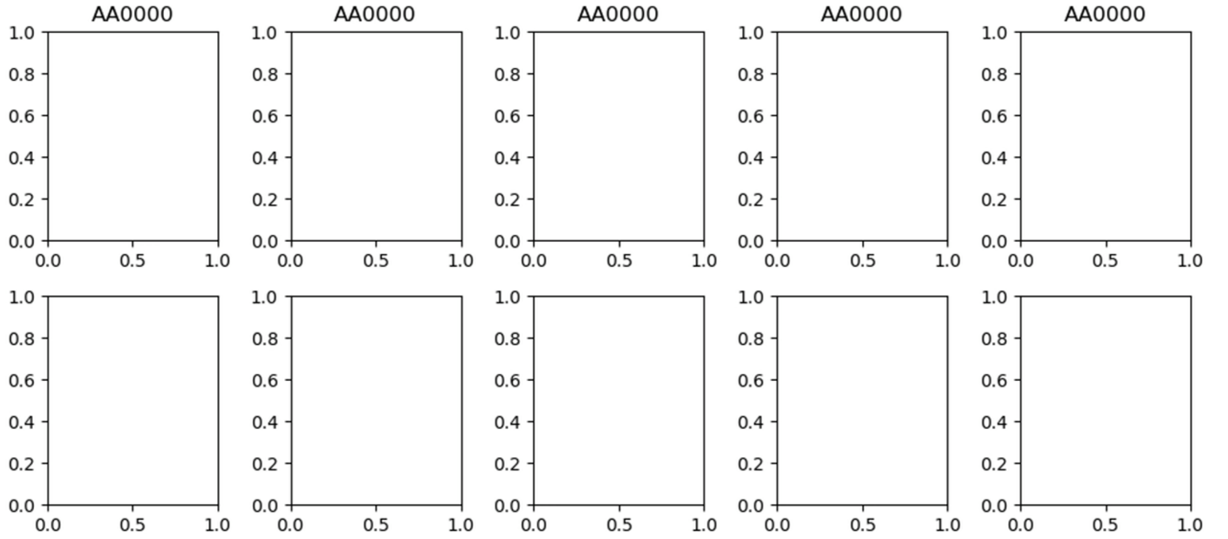
With TRN, we use where we think we are to predict what we think surface features should look like in an image and then locate the features in the image.

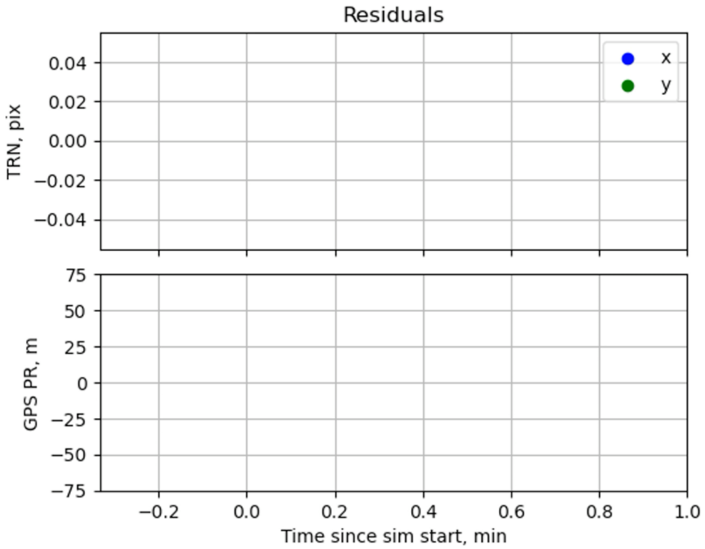




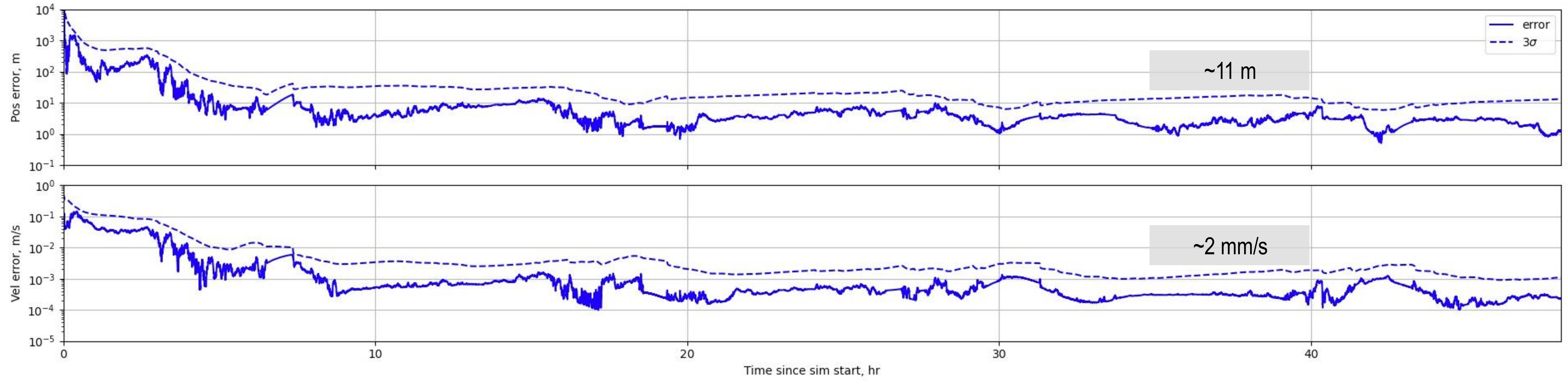
Flight Software-in-the-Loop Demo (TRN+GPS)

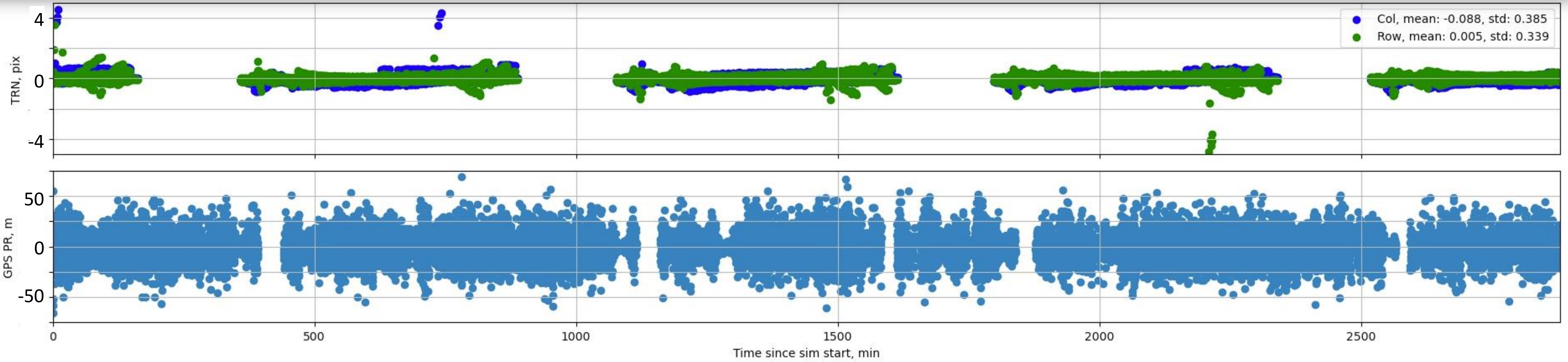






Flight Software in the Loop Simulation (TRN+GPS) shows excellent converged performance





autoNGC Summary

- autoNGC provides onboard autonomy – an enabler for future missions
- Plug-n-play cFS architecture allows customization and insertion of new capabilities, even in flight
- Low SWaP design is suitable for a wide range of space mission types
- Upcoming Milestones:
  - TRL 6 build of autoNGC software and hardware for autonomous navigation in lunar orbit targeted by Fall 2024
  - TRN/LiDAR Touch & Go Field Test in 2025
  - Flight test on CAPTSONE spacecraft (already in Lunar Gateway orbit) in 2025
- Additional capabilities in both software and hardware continue to be developed

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