NavCube3-mini Lunar GNSS Receiver

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ION GNSS+ 2023
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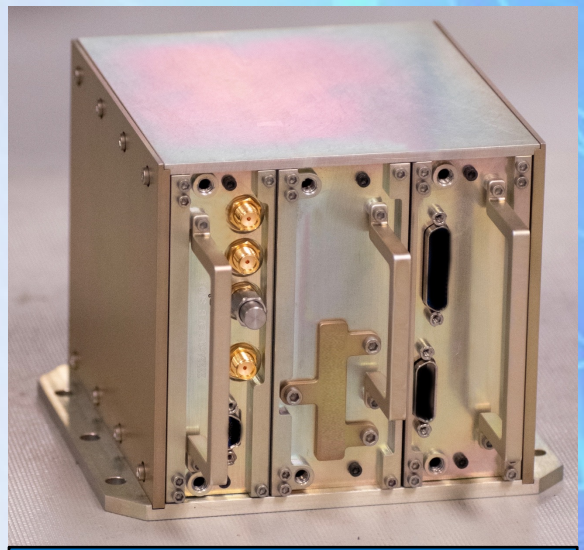
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Outline

- NavCube3-mini (NC3m) Lunar GNSS Receiver
  - Overview
  - Heritage
  - GEONS filter software
- Key target application - Lunar GNSS
- TRL6 Testing
- Sample Results
- Summary

NavCube3–mini (NC3m) GNSS Receiver – Overview (1)

- Low-SWaP GNSS receiver for all orbit regimes, especially **cislunar/lunar space**
  - High sensitivity receiver with fast acquisition
  - GPS L1C/A and L2C (or L5) currently available
  - Galileo E1 and E5a in development
  - On-orbit upgradable, FPGA-based radiation tolerant
  - Currently at TRL6 (L1C/A and L2C)
- Includes Goddard's onboard navigation filter software: Goddard Enhanced Onboard Navigation System (GEONS)
  - Enables high-altitude operation with sparse visibility and poor geometry
- Builds on the flight proven (TRL9), high altitude, Magnetospheric Multiscale (MMS) Mission Navigator GPS receiver

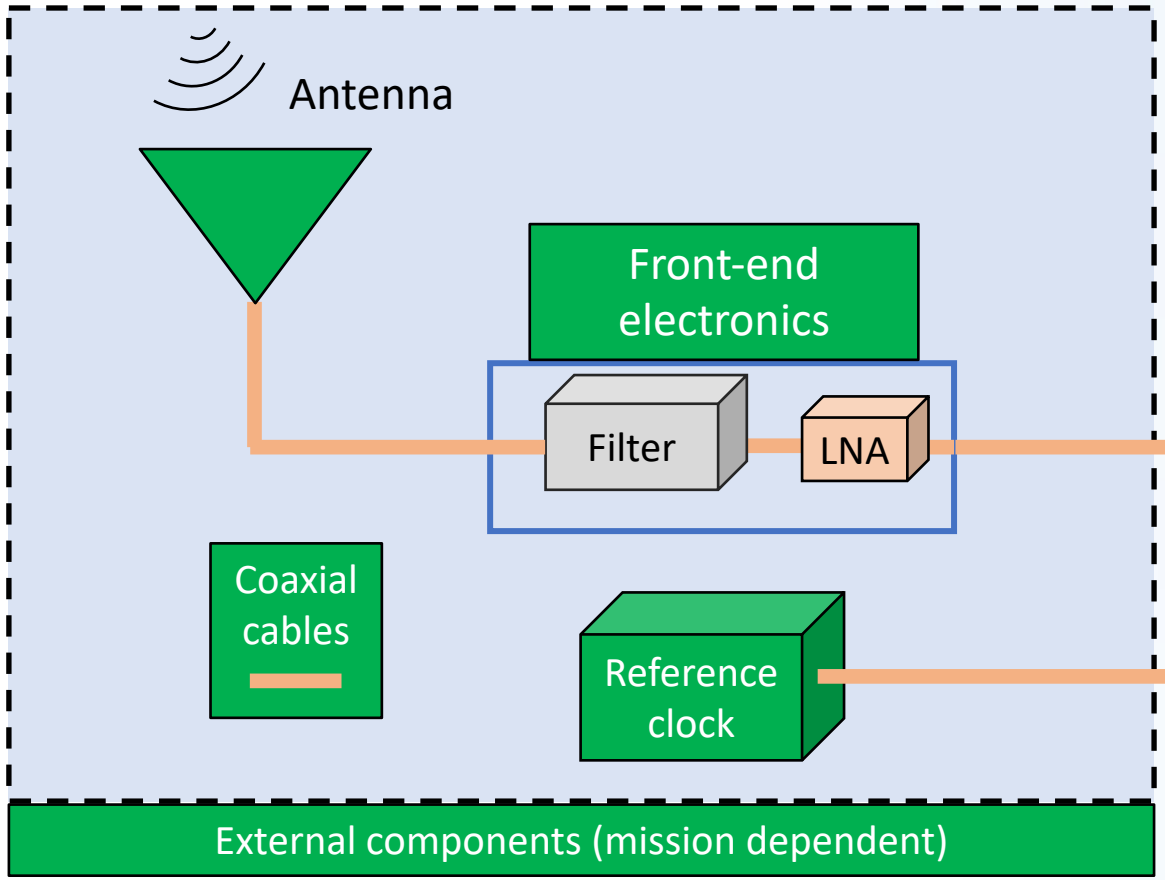


NC3m GNSS Receiver

NC3m – Overview (2)

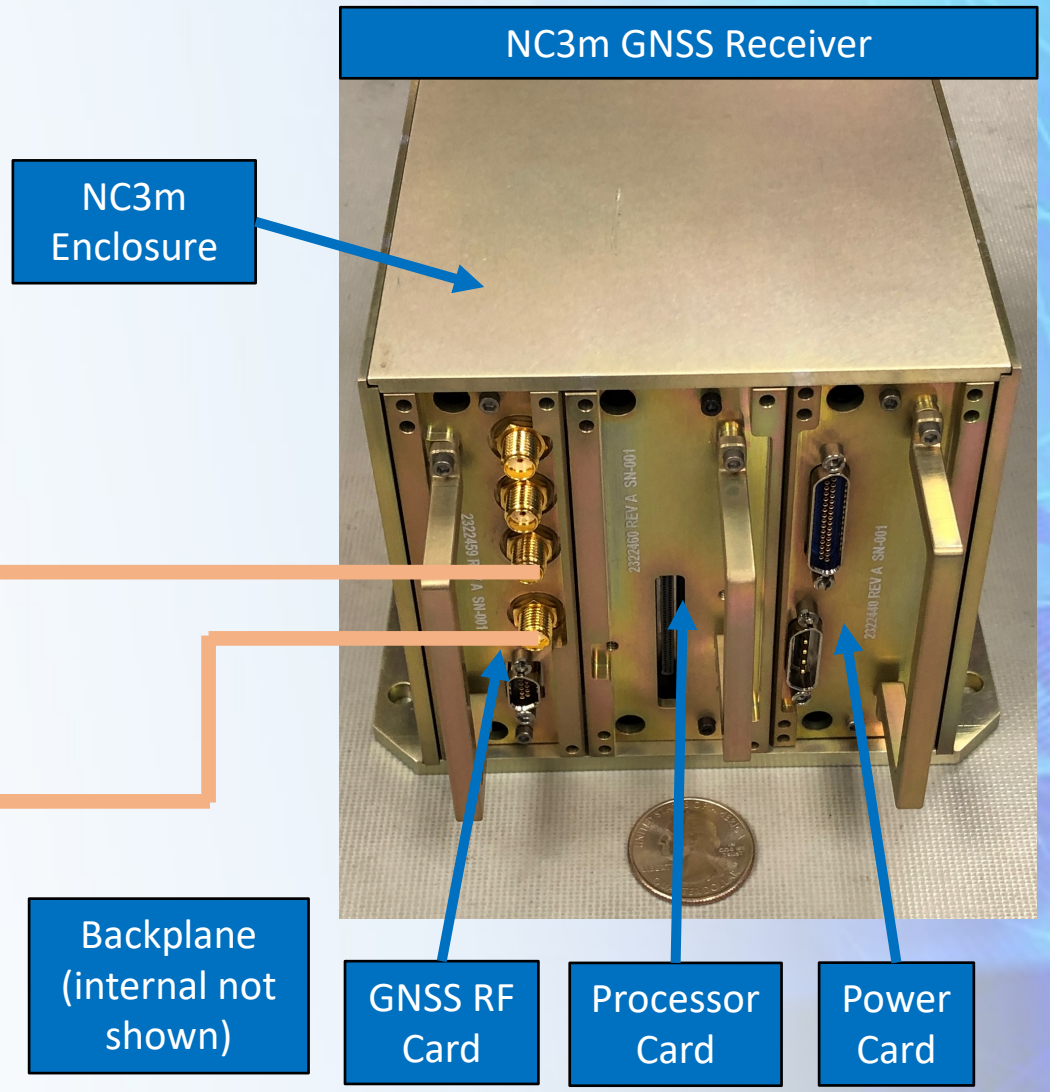
NC3m Receiver External Interfaces:

- L-band RF signal
- External reference oscillator (internal option available)
- 1PPS out
- RS422 command/telemetry
- Standard 28V bus power



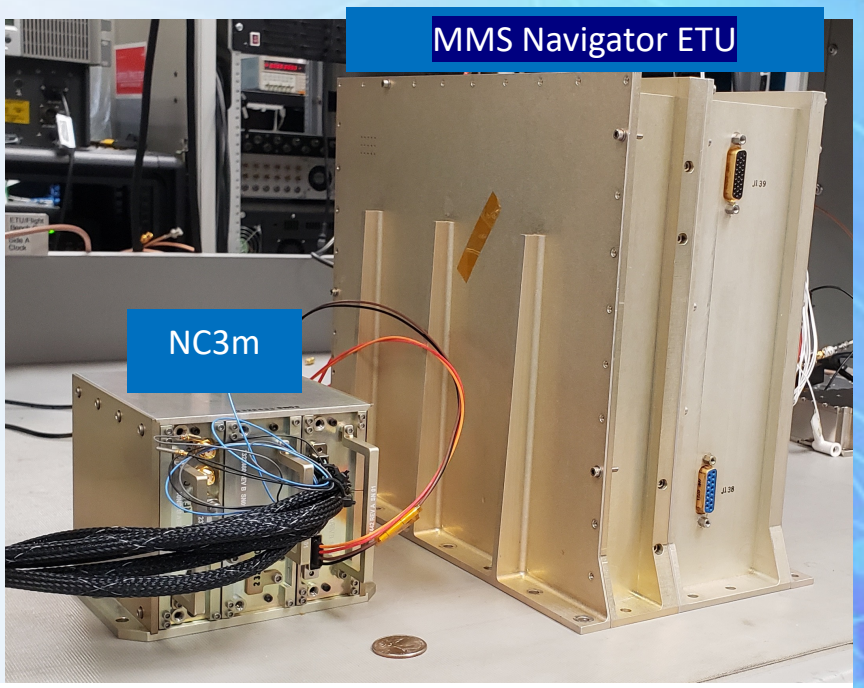
NC3m Receiver SWaP

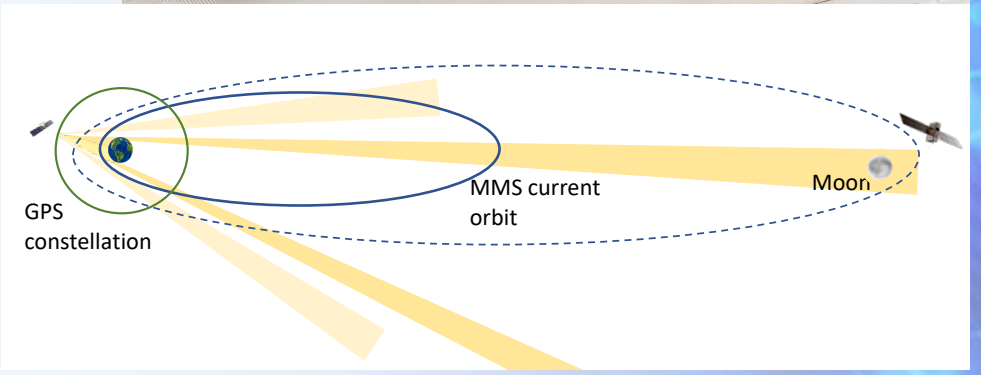
- Size: WxDxH: 5.0”x5.0”x4.0”, Mass: 1.5 kg, Power: 13 W



NC3m – MMS Heritage and Improvements

- NC3m builds on the flight proven (TRL9) GSFC Magnetospheric Multiscale Mission (MMS) Navigator GPS receiver
  - A weak signal capable receiver enabling GPS transmitter sidelobe tracking. Includes GEONS (version 2) navigation filter
  - Currently operational (8 receivers) since 2015 in elliptic orbit with apogee reaching >29 Earth radii, approximately halfway to the moon
- NC3m includes multiple improvements over MMS Navigator
  - Meets or exceeds MMS-Navigator level-of-performance using L1C/A
  - Reduced SWaP
  - Dual frequency L1C/A and L2C (or L1C/A and L5) capable
  - Multi-GNSS capable E1 and E5a (in development)
  - On-orbit reprogrammable/upgradable
  - Includes updated GEONS version 3, enabling high-performance lunar navigation
- MMS-Navigator on-orbit performance suggests GNSS can provide excellent navigation performance at lunar distance
- MMS on-orbit data used by NC3m team to calibrate updated GNSS high-altitude and lunar simulations





GNSS Receiver Benefits for Lunar Applications

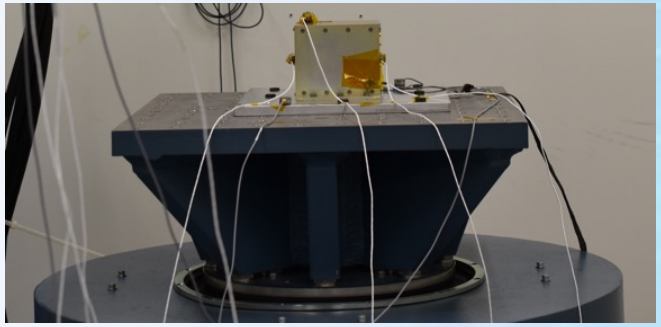
- Leverage existing, always-on, Earth-based navigation and timing infrastructure
- Provide reliable onboard, real-time, autonomous navigation
- Support Positioning, Navigation, and Timing (PNT) services
- Support lunar relay and lunar communication and navigation architecture
- Reduce ground support and network loading
- Reduce operation cost
- Reduce risk for commercial GNSS receiver vendors
- Support science applications through high accuracy Positioning, Navigation, and Timing

Lunar GNSS feasibility demonstrated using high fidelity analyses and Hardware-in-the-Loop simulations

Technology Readiness Level 6 (TRL6) Testing

- Technology Readiness Levels commonly used by NASA and elsewhere for tracking technology maturation.
  - TRL6 is a critical level which requires *demonstration of a system/subsystem model or prototype in a relevant environment*
- Conducted on a flight-like NC3m Engineering Test Unit (ETU), using an ultra-stable reference oscillator and suitable front-end electronics
- High fidelity hardware-in-the-loop simulations developed as the comprehensive performance tests
  - Covered LEO, GEO, and lunar scenarios
  - Calibrated against MMS flight data
  - Ionosphere, broadcast, maneuver errors omitted because focus was on hardware performance. Impact of these errors is mild, mission dependent.
- Completed TRL6 testing in July 2022
  - Performance testing at NASA Goddard Formation Flying Testbed, a world-class spaceflight GNSS test facility
  - Conducted vibration, thermal vacuum, and EMI testing at Goddard environmental test facilities
- *Excellent performance demonstrated, results well matched to predictions, and passed test criteria*
- Passed TRL6 Assessment Review in Dec 2022

Vibration table with NC3m ETU



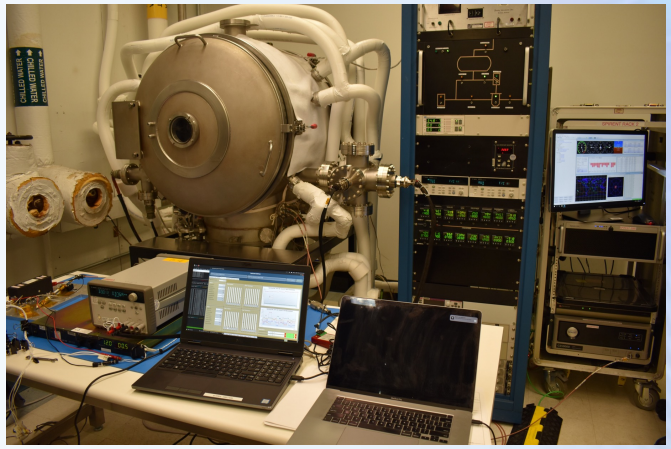
Cesium time standard



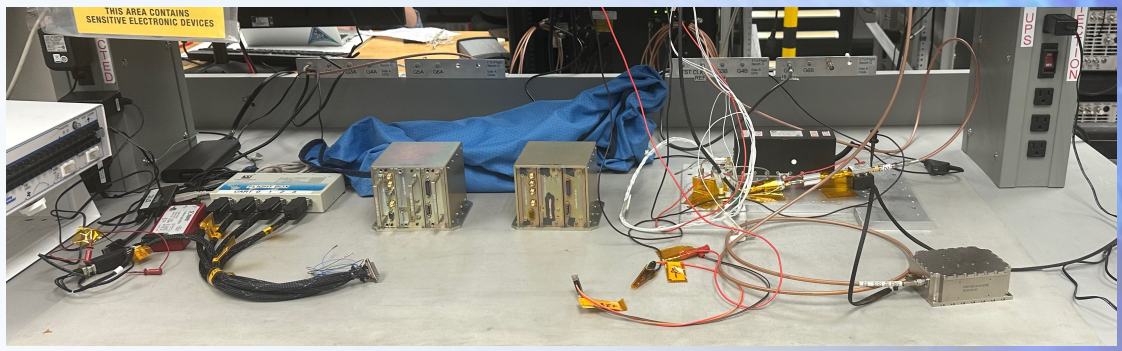
GNSS Simulator



Thermal Vacuum Chamber containing NC3m ETU

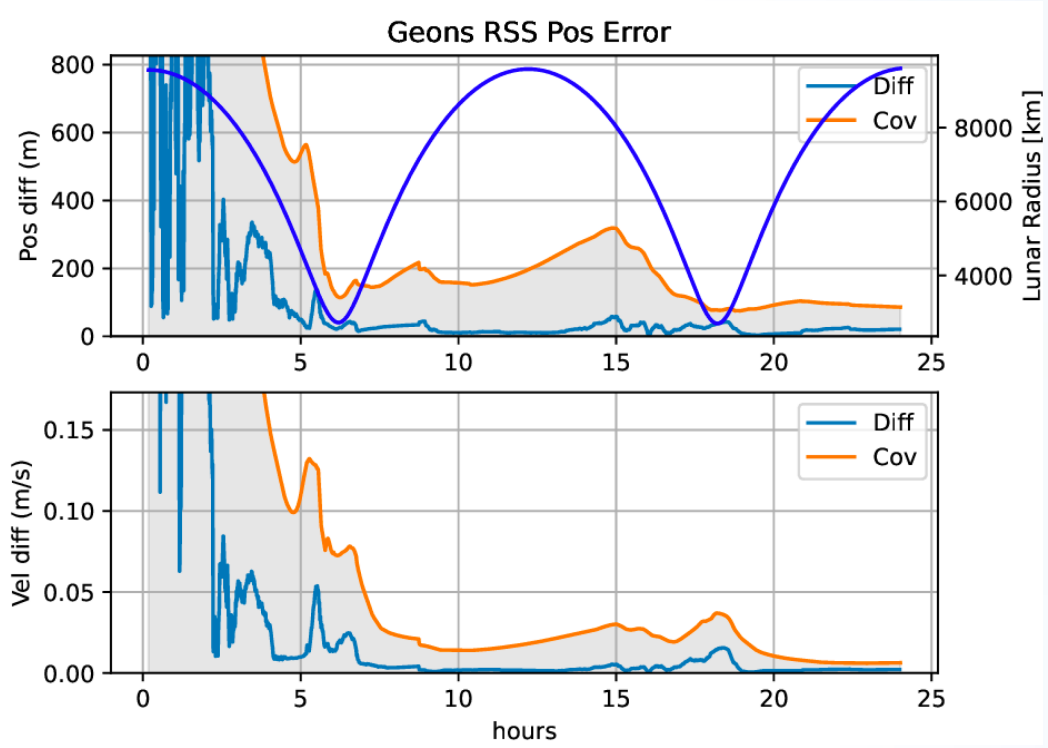


Bench top performance testing with NC3m ETU (right) and a development unit

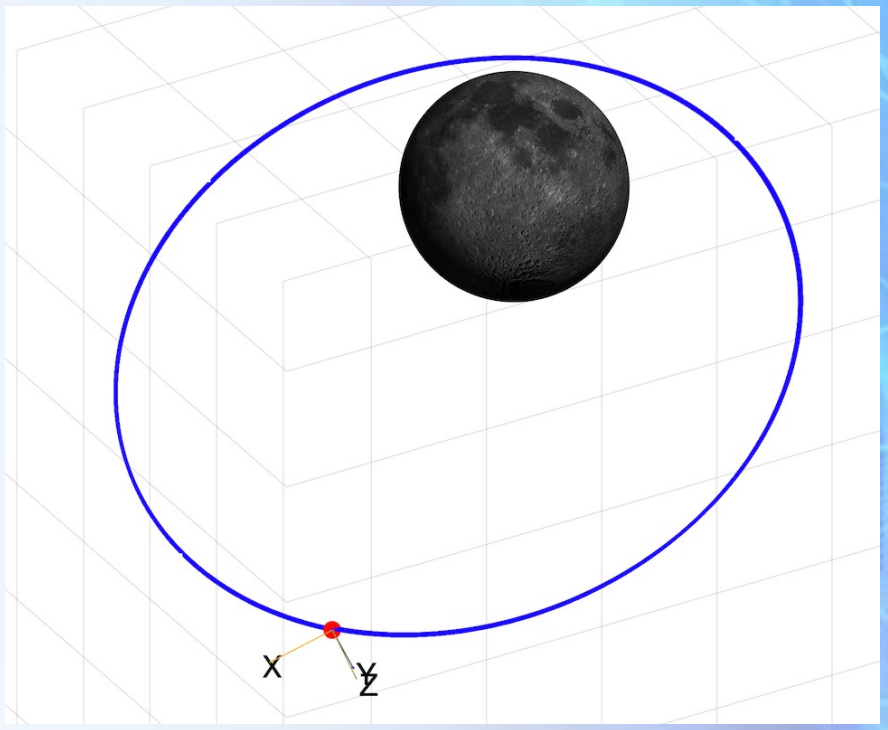


Example TRL6 test results: lunar orbit

- Reference 12-hour Elliptical lunar frozen-type orbit (ELFO) with apolune south pole coverage
- Uses simple Earth-pointed 16dBi-peak high-gain antenna model
- Achieves <100m, <1cm/s RSS error at 24 hours



GEONS RSS errors (blue) and 3x RSS covariance diagonal (orange) with orbit radius (also blue)

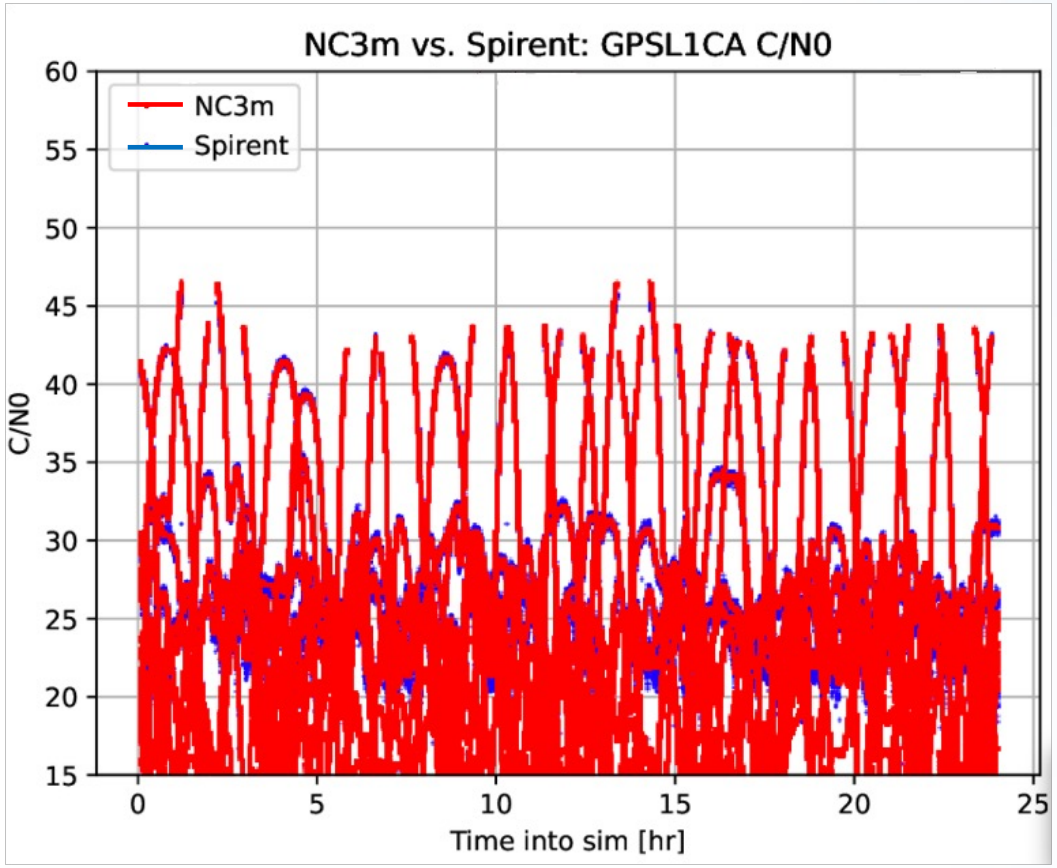


Notional 12-hour frozen orbit with apolune south pole coverage

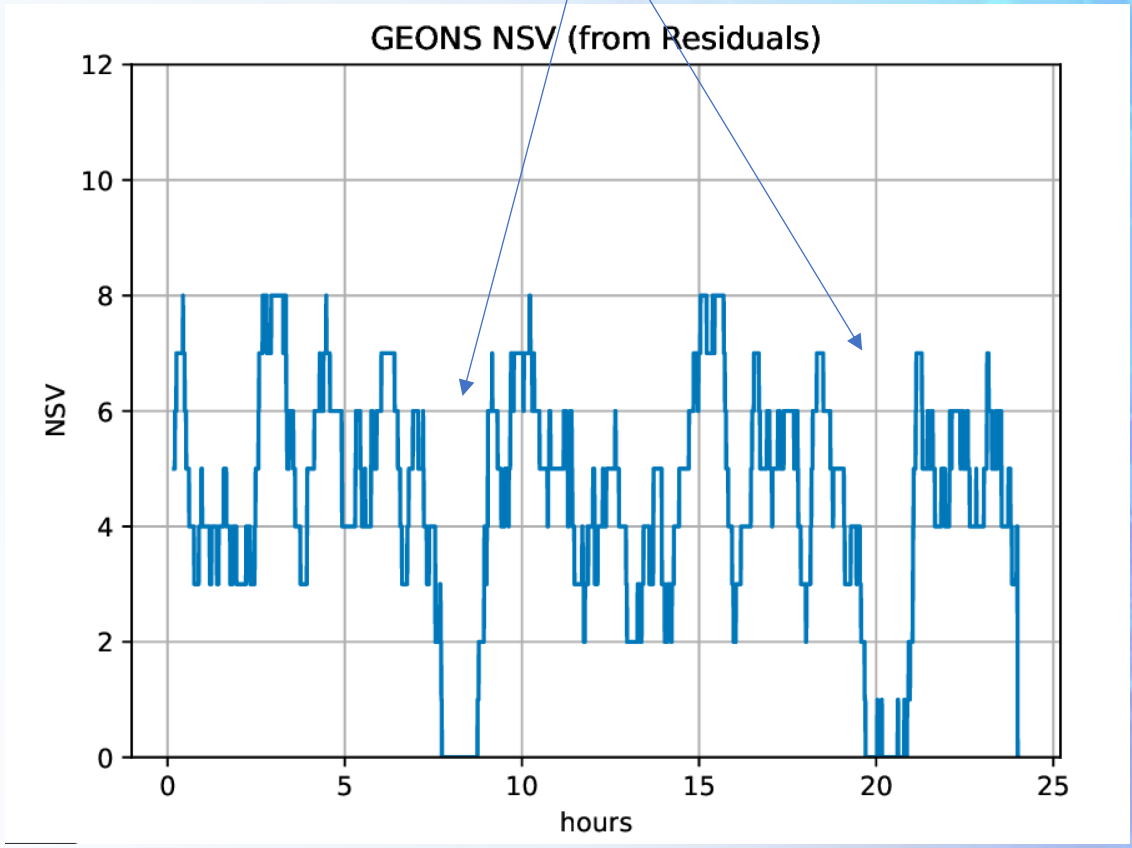
Moon Image from: https://astropedia.astrogeology.usgs.gov/download/Moon/LRO/LROC_WAC/thumbs/Moon_LRO_LROC-WAC_Mosaic_global_1024.jpg

Example TRL6 test results: lunar orbit

Drops to zero signals correspond to lunar occultations (excluded by GEONS filter, but not modelled by simulator)



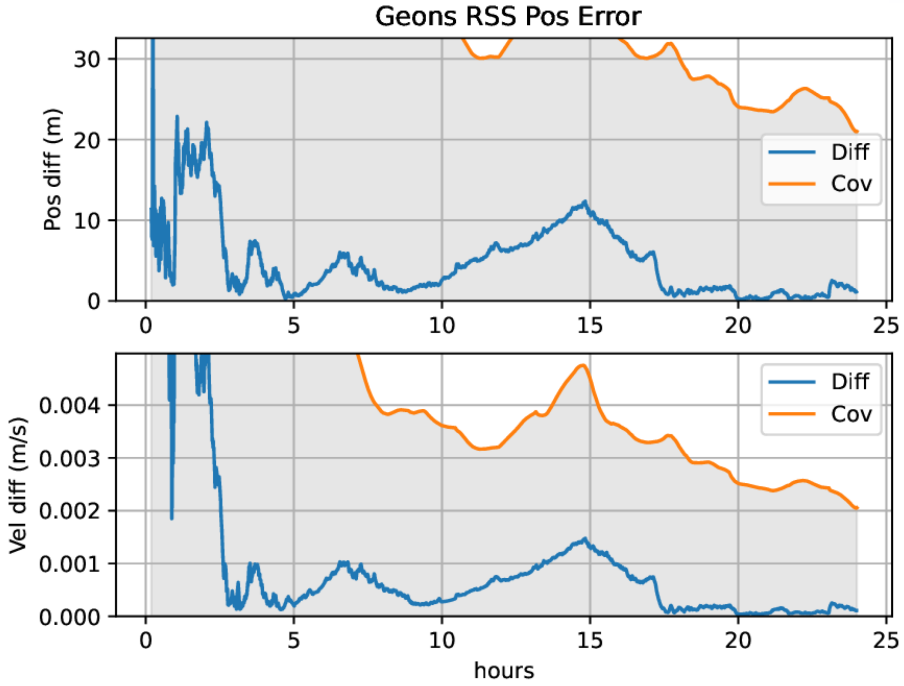
Simulated vs. tracked signal to noise ratio



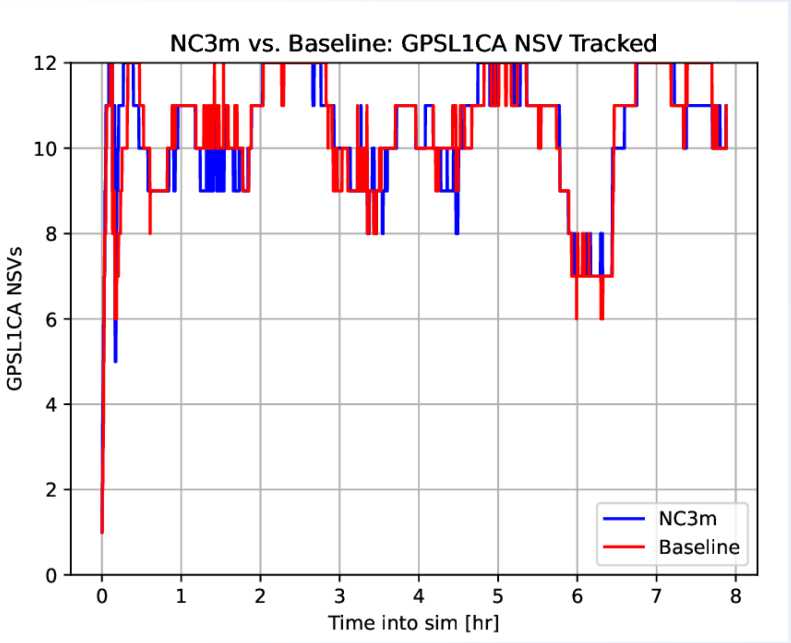
Number of GPS signals processed by GEONS

Example TRL6 test results: GEO orbit

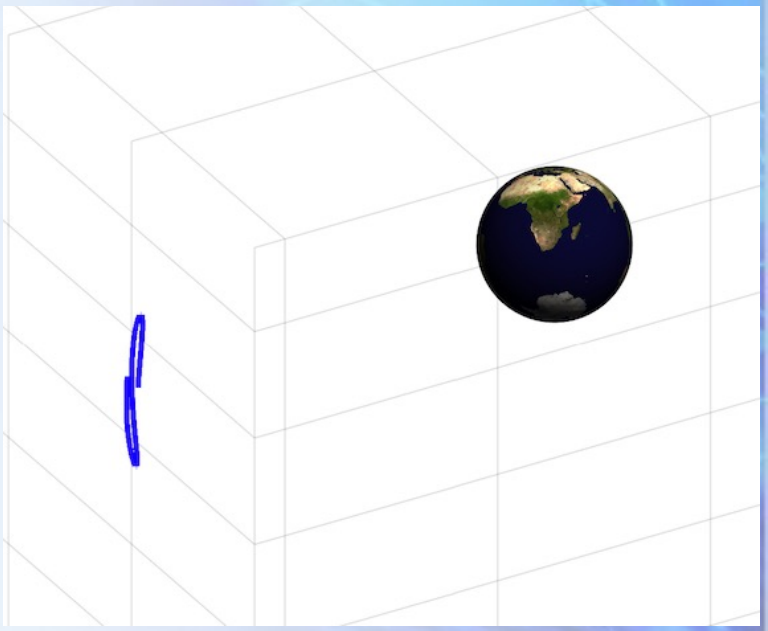
- Simple nadir pointed 10dBi high-gain antenna
- Achieves <30m, 3mm/s RSS error at 24 hours



GEONS RSS errors (blue) and 3x RSS covariance diagonal (orange)



Number of signals tracked vs. performance baseline

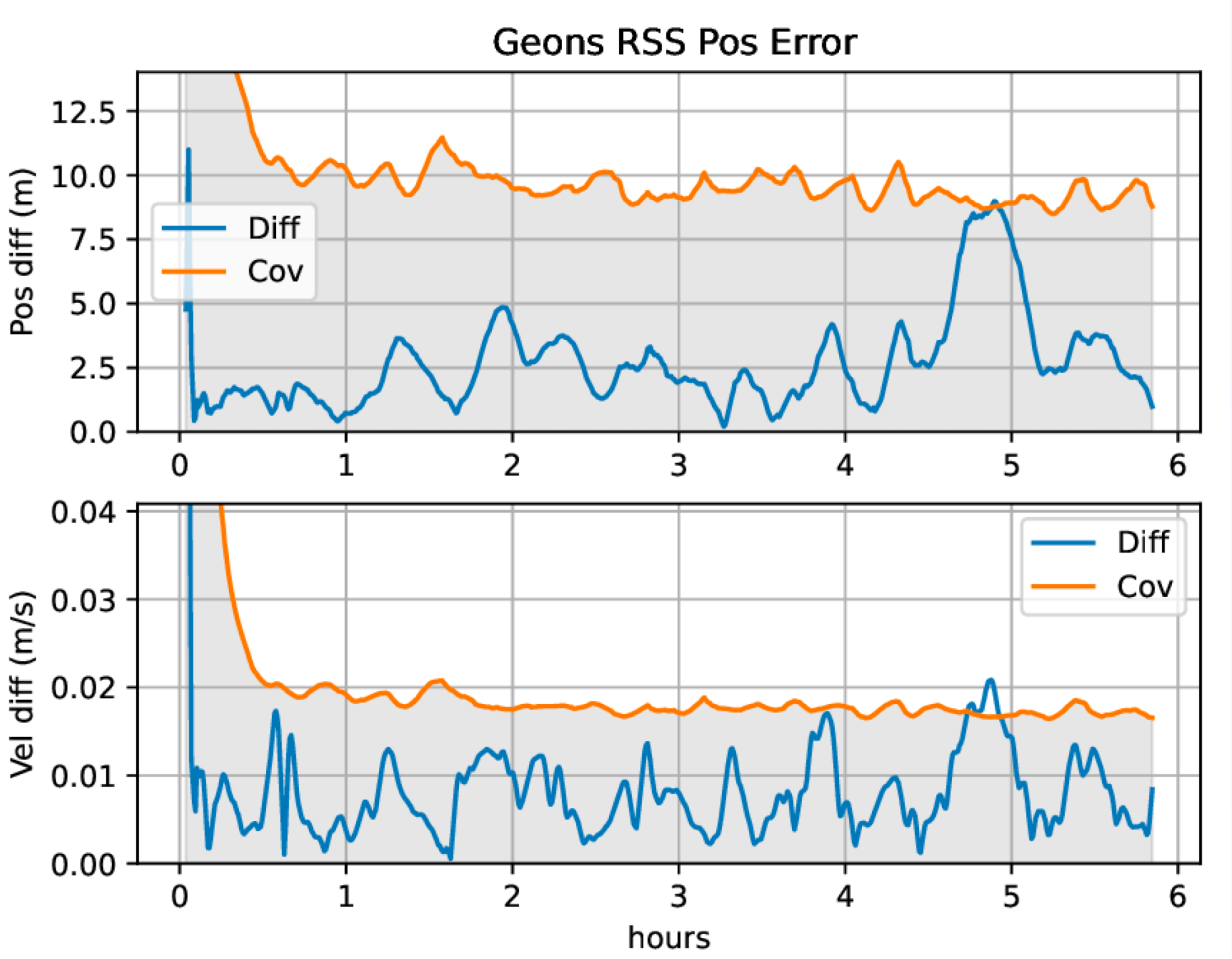


Notional GEO orbit

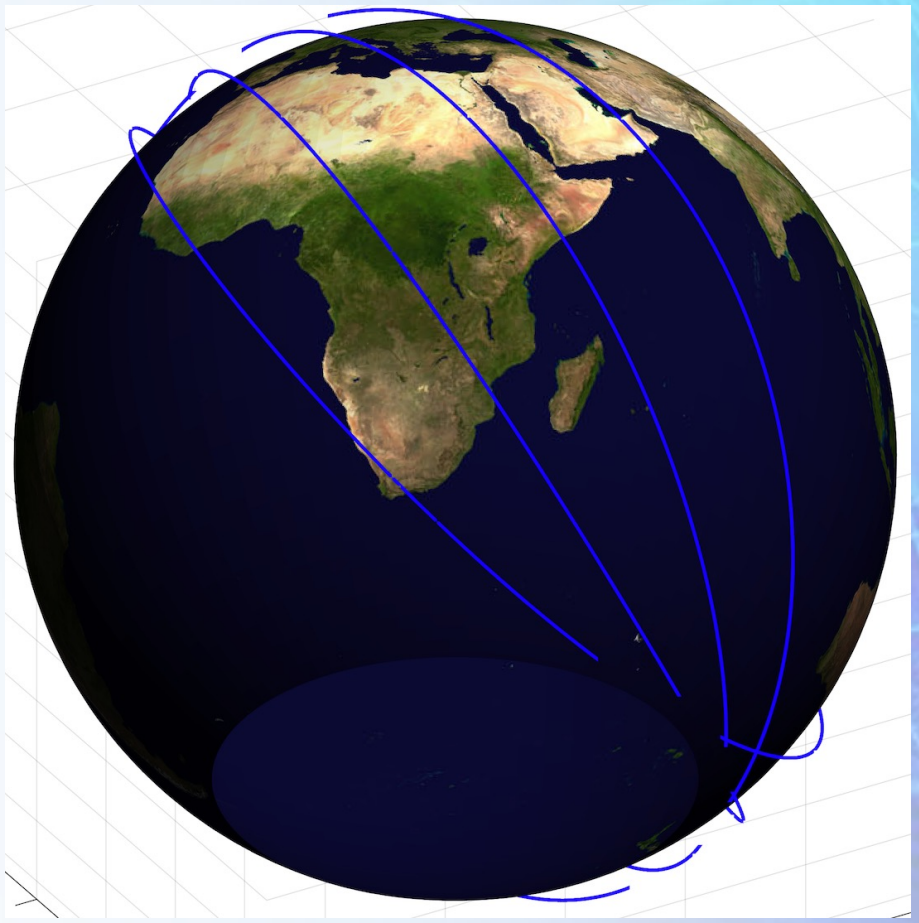
Earth Image from: https://eoimages.gsfc.nasa.gov/images/imagerecords/57000/57752/land_shallow_topo_2048.jpg

Example TRL6 test results: LEO orbit

- Simple zenith pointed patch antenna model



GEONS RSS errors (blue) and 3x RSS covariance diagonal (orange)



Notional LEO orbit

Earth Image from: https://eoimages.gsfc.nasa.gov/images/imagerecords/57000/57752/land_shallow_topo_2048.jpg

Summary

- Developed NavCube3-mini (NC3m) GNSS receiver for all Earth orbit regimes, especially targeting cislunar/lunar space applications
  - Low-SWaP
  - Dual-frequency, multi-GNSS capable
  - Heritage from TRL9 MMS-Navigator (in high apogee, highly elliptic orbit)
- Completed TRL6 test campaign and achieved TRL6
  - Conducted vibration, thermal vacuum, and EMI testing
  - Excellent performance demonstrated on high-fidelity LEO, GEO, and Lunar simulations in relevant environment
- NC3m is baselined for two upcoming missions: one LEO and one lunar
- A US patent awarded for this technology (August 2022)
- Continuing to work on NC3m GNSS receiver and GEONS filter enhancements