Keeping the universe connected.

NASA Update to WG-B

MMS GPS Performance at 29.34 Re (50% of way to the moon)

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www.nasa.gov

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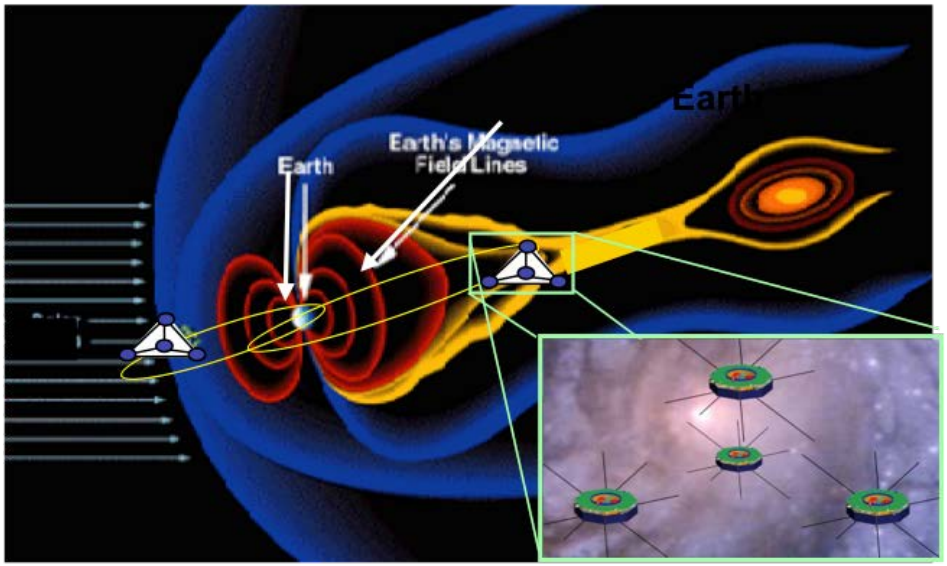
NASA's Magnetospheric MultiScale (MMS) Mission

- Discover the fundamental plasma physics process of reconnection in the Earth's magnetosphere.
- Coordinated measurements from tetrahedral formation of four spacecraft in highly eccentric orbits with typical formation spacing of 20-40 km at apogee
- Flying two mission phases & 3 orbit scenarios
  - Phase 1: 1.2x12 R_E (magnetopause), Mar '14-Feb '17
  - Phase 2B: 1.2x25 R_E (magnetotail), May '17-Feb '19
  - Extended Mission: 1.2x29.34 R_E (magnetotail), Higher apogee to reduce eclipse time, Feb '19-Present



Four Stacked MMS Spacecraft

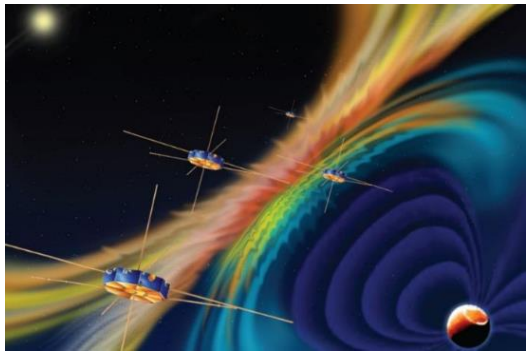
Using GPS above the GPS Constellation: NASA GSFC MMS Mission

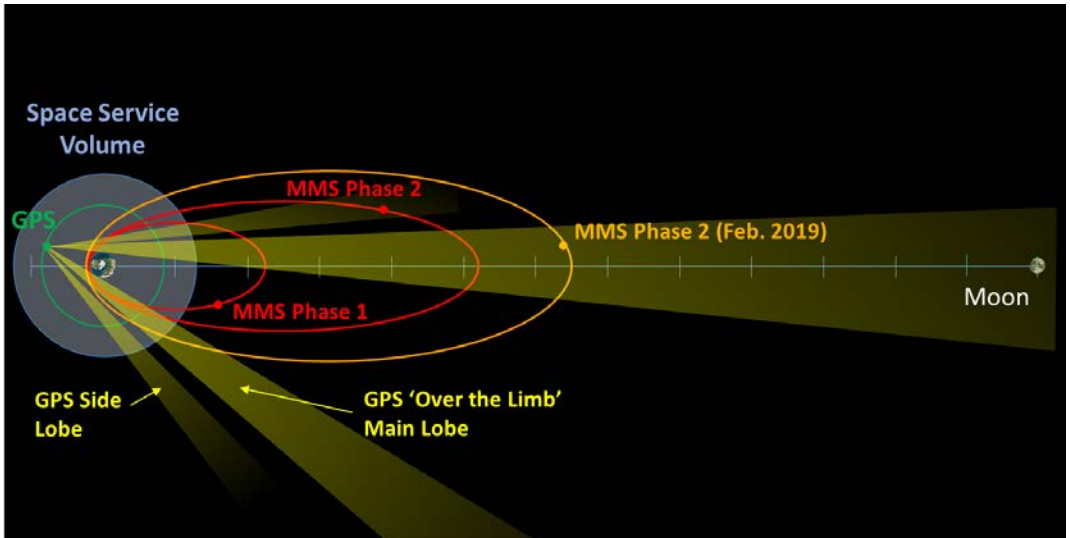
Magnetospheric Multi-Scale (MMS)

- Launched March 12, 2015
- Four spacecraft form a tetrahedron near apogee for performing magnetospheric science measurements (space weather)
- Four spacecraft in highly eccentric orbits
  - Phase 1: 1.2 x 12 Earth Radii (Re) Orbit (7,600 km x 76,000 km)
  - Phase 2B: Extends apogee to 25 Re (~150,000 km)
  - Extended Mission: Feb '19 Apogee raising to 29.34 Re **(50% of way to Moon!)**

MMS Navigator System

- GPS enables onboard (autonomous) navigation and near autonomous station-keeping
- MMS Navigator system exceeds all expectations
- At the highest point of the MMS orbit Navigator set Guiness world record for the highest-ever reception of signals and onboard navigation solutions by an operational GPS receiver in space
- At the lowest point of the MMS orbit Navigator set Guiness world for fastest operational GPS receiver in space, at velocities over 35,000 km/h





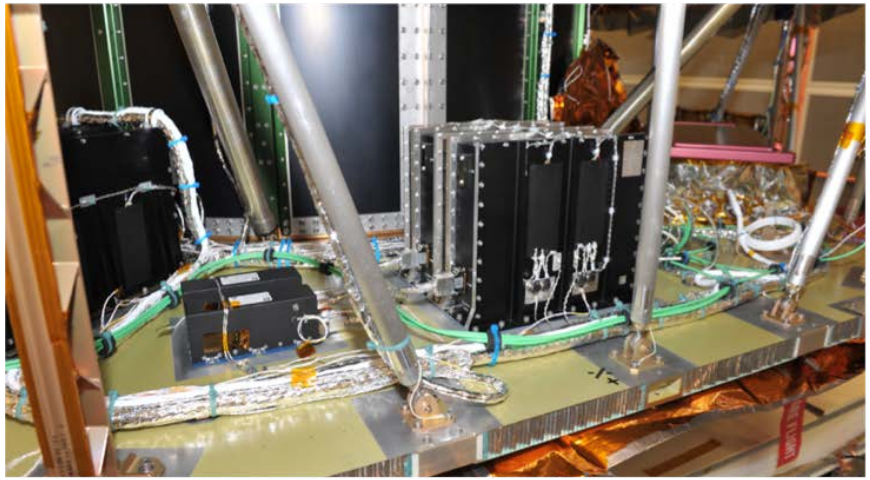
MMS Navigator GPS Hardware

- GPS hardware all developed and tested at GSFC. Altogether, 8 electronics boxes, 8 USOs, 32 antennas and front ends.
- Tracking sensitivity down to ~22 dB·Hz.

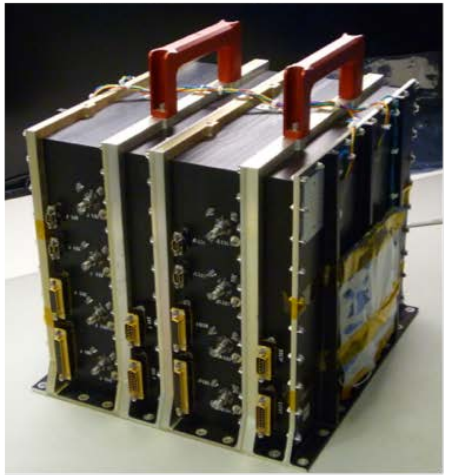
Ultra Stable Osc.

Front end electronics assembly

GPS antenna

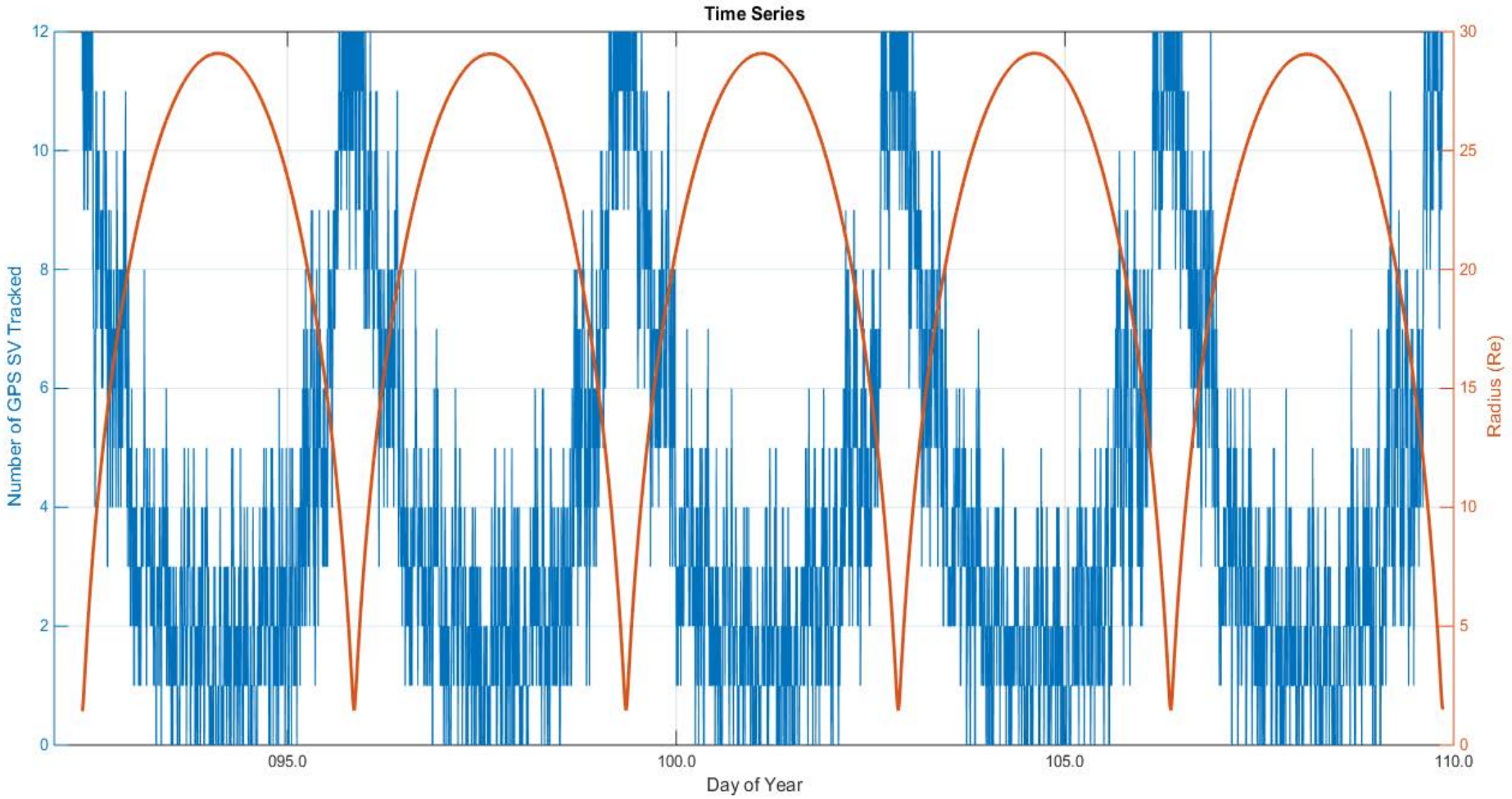


Receiver and USO on spacecraft deck

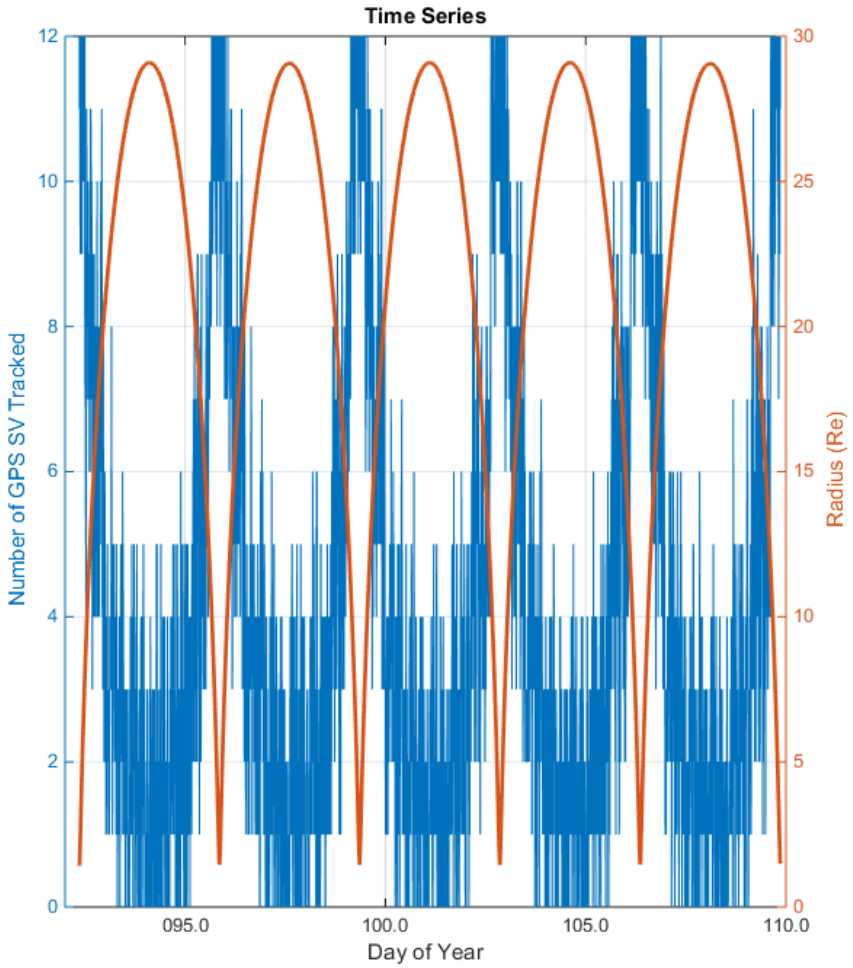


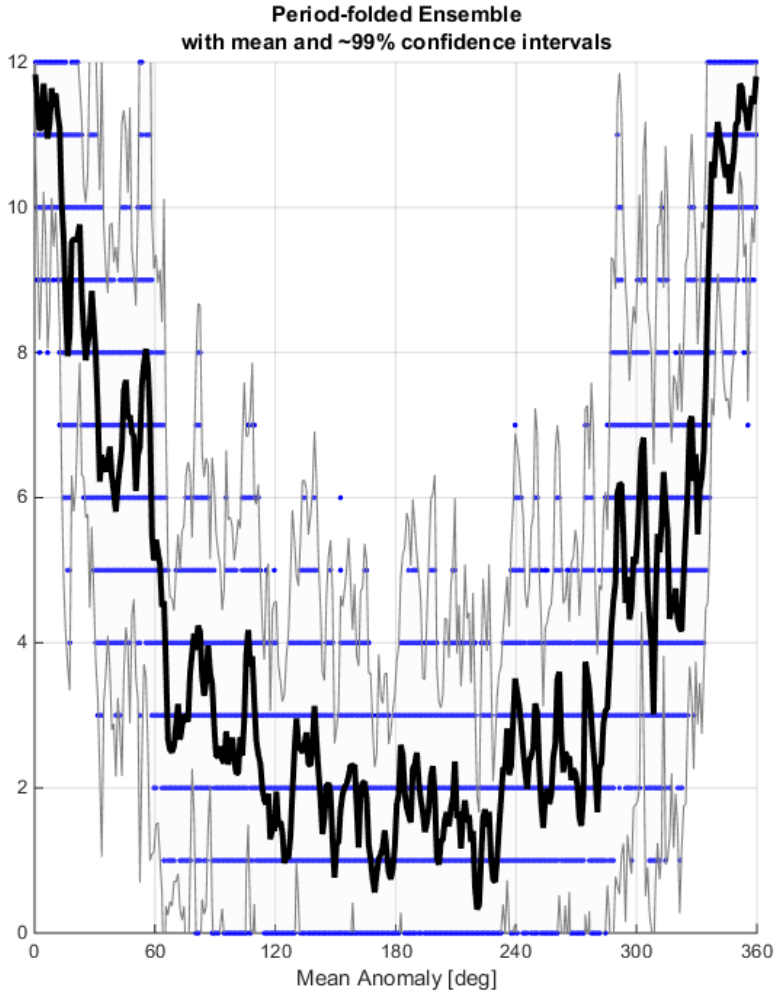
Redundant receiver electronics

Signal Tracking Performance: 29.34 Re



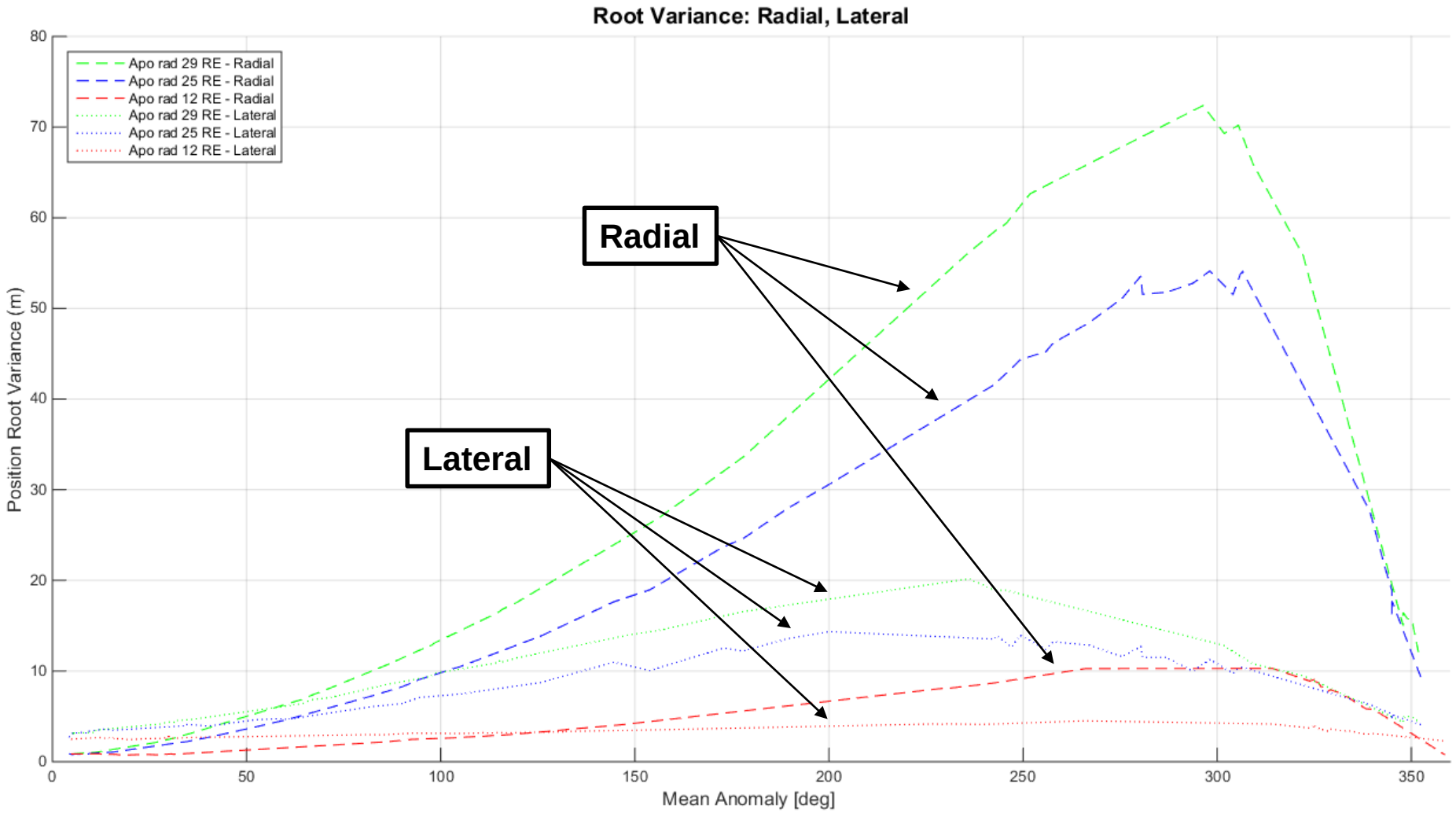
Signal Tracking Performance: 29.34 Re



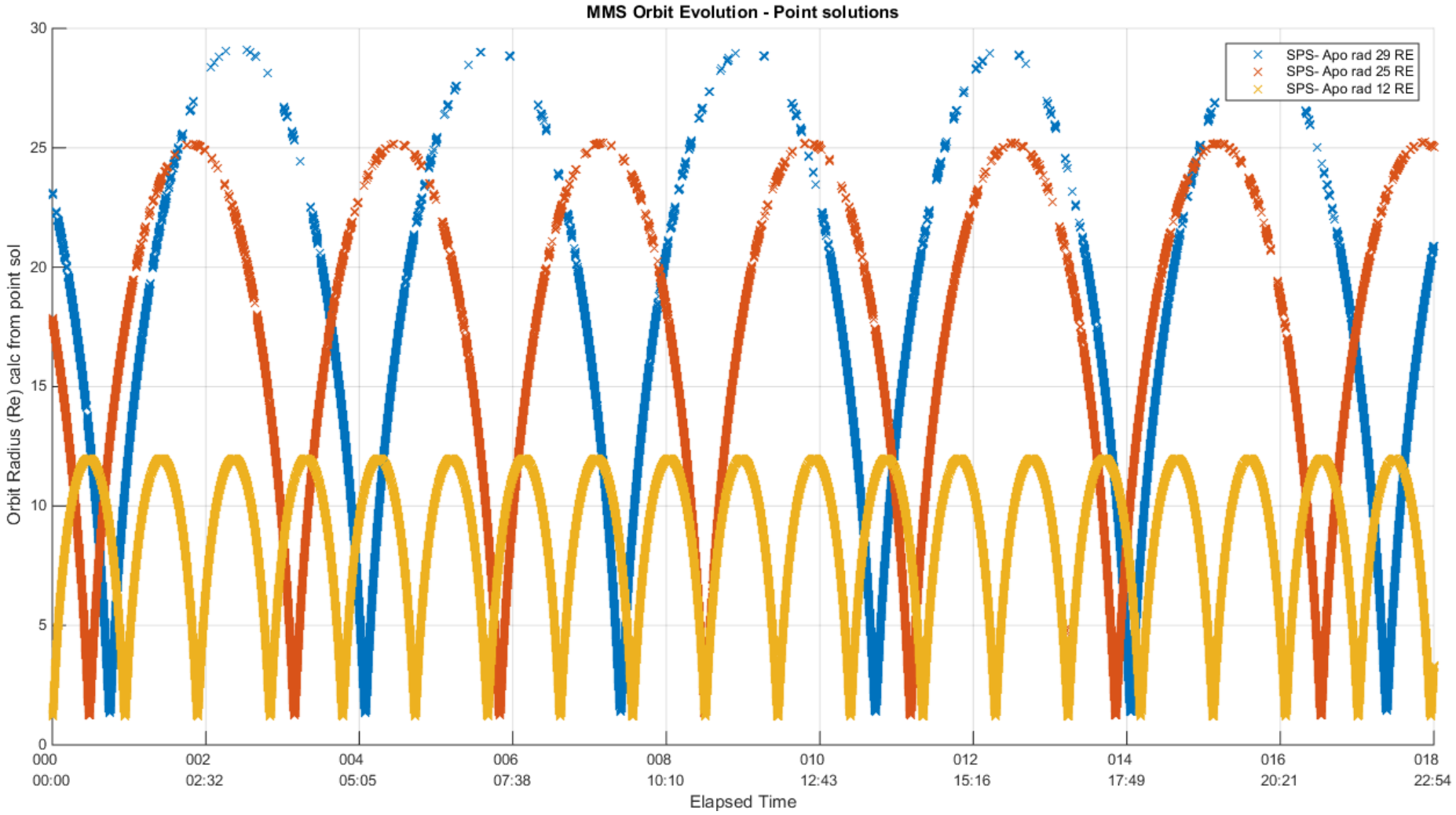


Average 1 Signal in View at Apogee

Position Navigation Performance
12 Re, 25 Re, 29 Re



Point Solution Evolution
12 Re, 25 Re, 29 Re



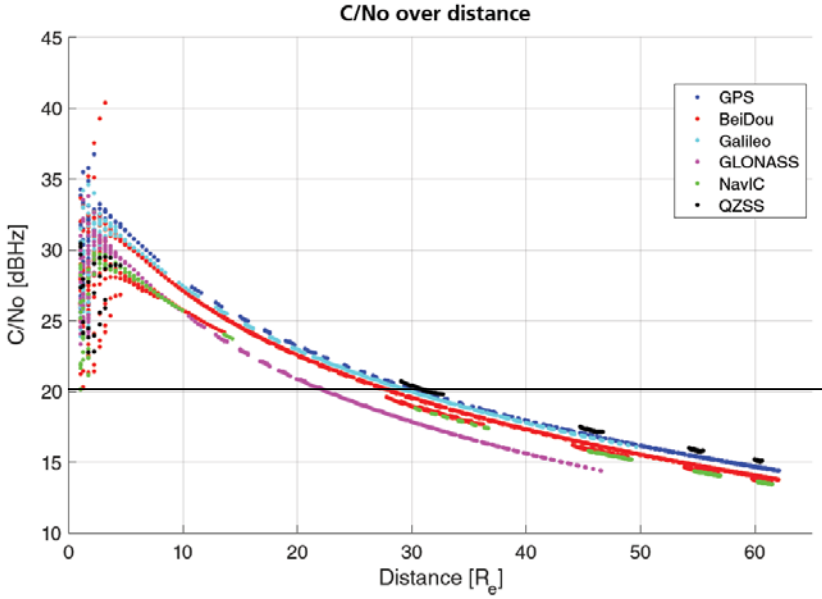
Comparison of MMS 29.34 Re data with SSV Booklet Lunar Trajectory Analysis

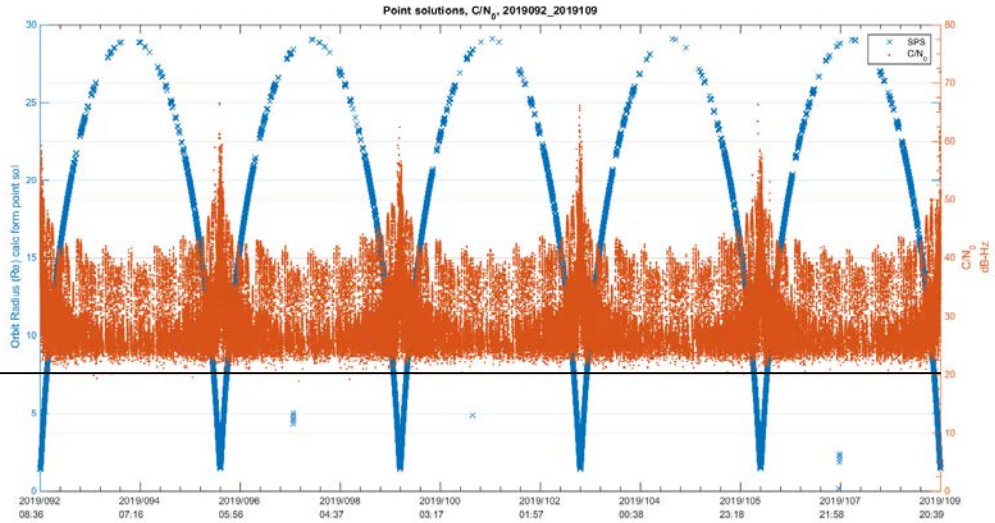
Booklet Lunar Trajectory Results

- Signal availability drops out around 30 Re; Cause: signals drop below assumed 20 dBHz tracking threshold

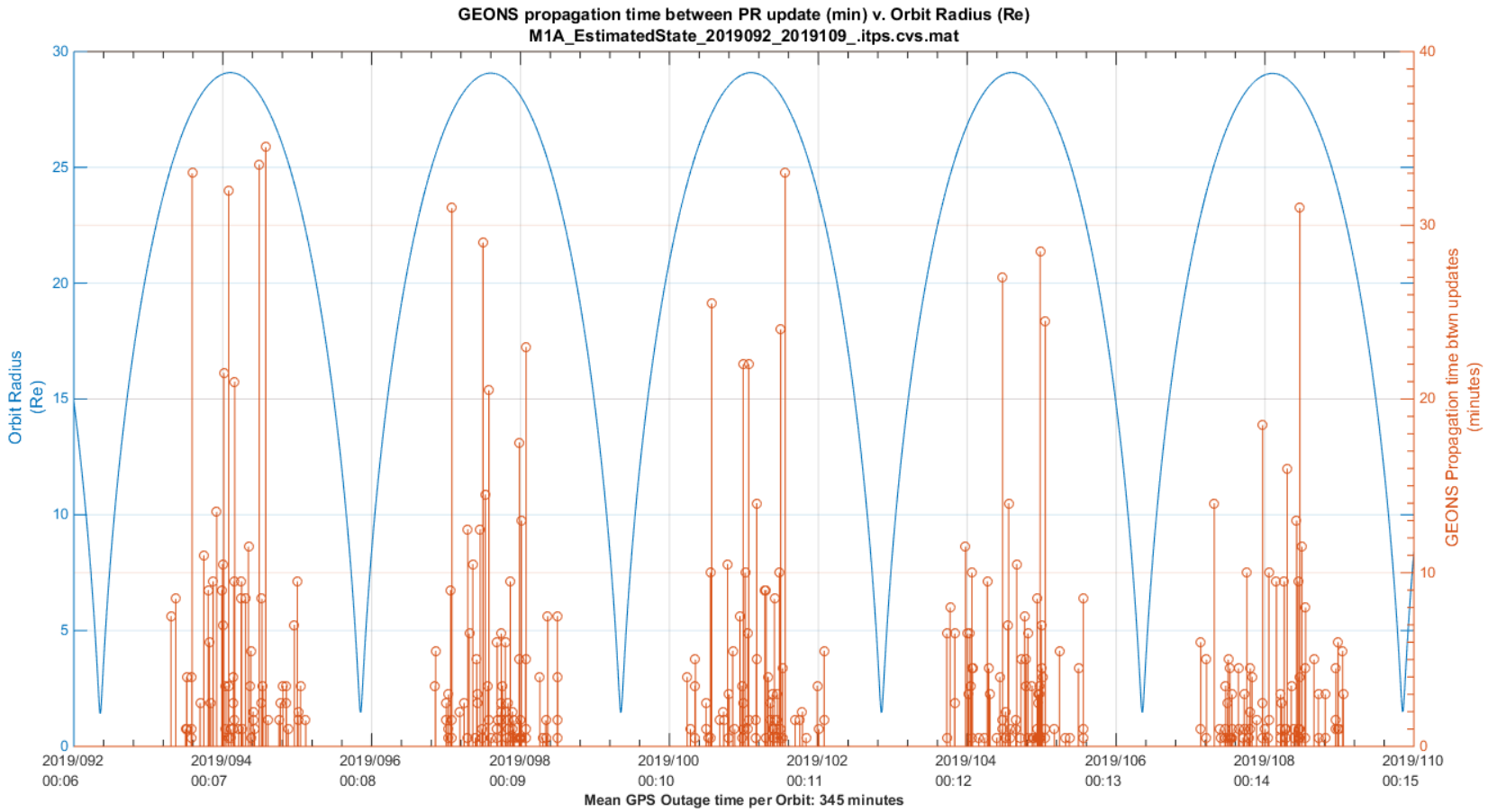
MMS 29.34 Re Results

- Signal availability begins dropping near 29.34 RE; Cause: Tracking threshold of MMS system is around 20 dBHz
- Future missions could improve GNSS availability at 29 Re and at lunar distances by using higher gained antennas and/or more sensitive GNSS receivers





GPS Outage Results at 29.34 RE



MMS Orbit period ~ 3.5 days (~5040 min)
GPS mean outage per orbit: 345 min
Signal availability: ~93%

Conclusions

- In February 2019, MMS constellation raised to 29.34 Re apogee—approximately 50% of the way to the moon
- MMS continues to exhibit outstanding GPS performance throughout its orbit, despite nearing the tracking threshold of Navigator receiver/antenna system at apogee
- Data from MMS closely matches SSV Booklet signal loss around 30 Re as illustrated in the lunar trajectory analysis
- Higher gained antenna and/or more sensitive GNSS receivers can extend signal availability beyond 30 Re
- MMS mission provides solid data to enable the design of missions that can reliably use GNSS systems out to lunar distances