Initial Results of the **S**oftware-driven **N**avigation for **S**tation Experiment

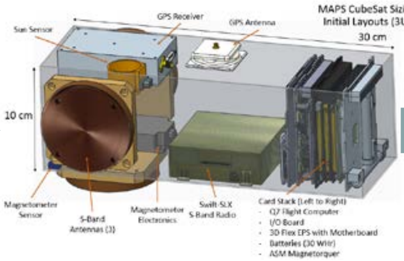
(t,r,v)$_{ISS}$

MAPS Navigation Packet + Pseudolite Signal

Packet Time of Flight and Pseudorange

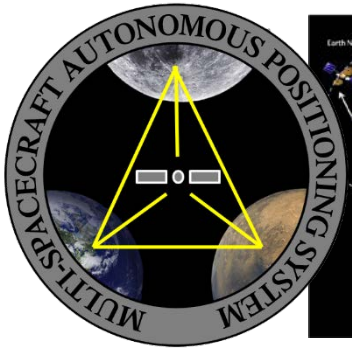
ISS

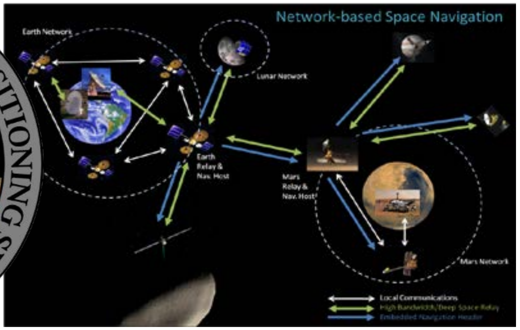
SCaN Testbed



MAPS Ground Node

Estimated Position and Velocity of Ground Node





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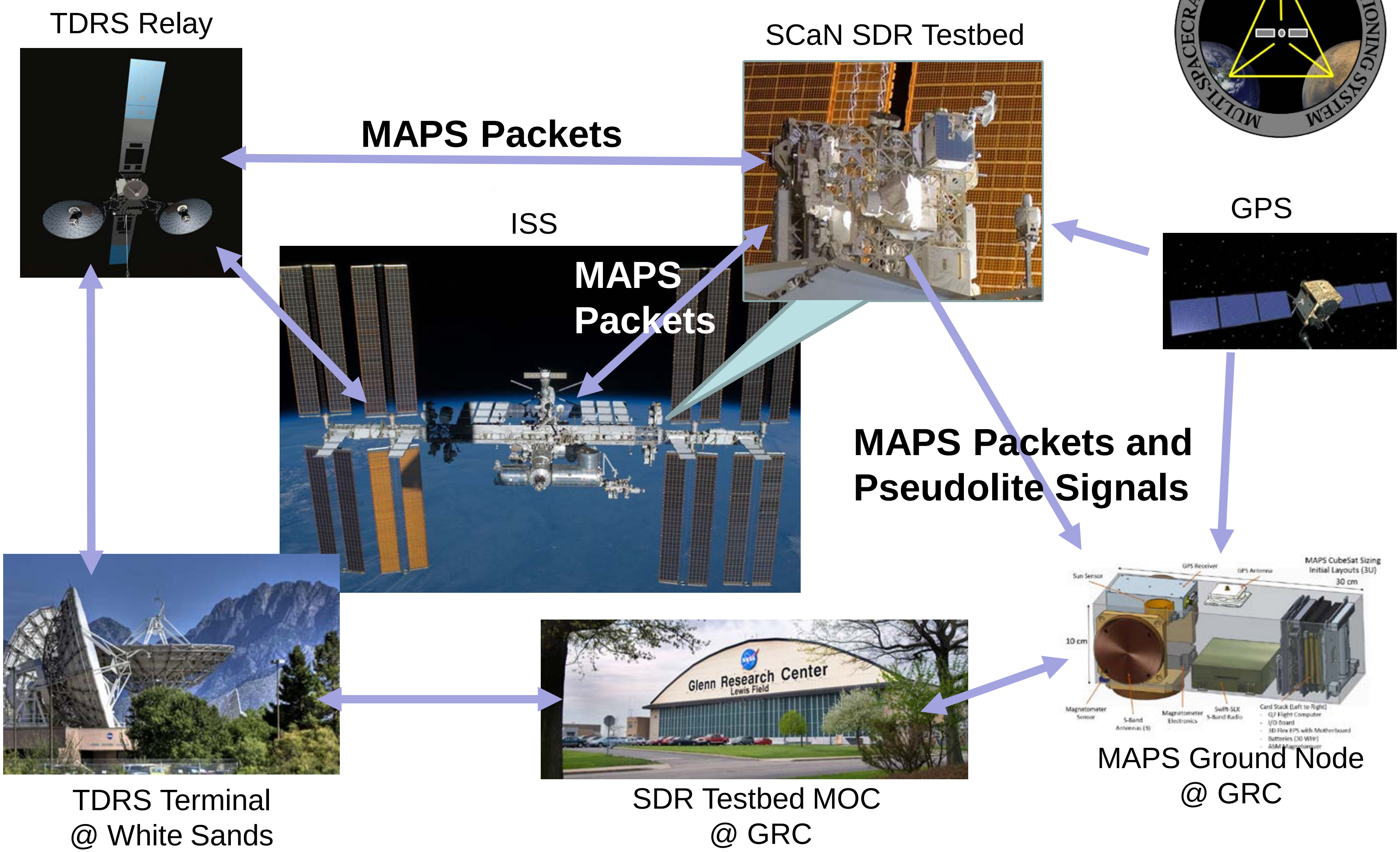
AIAA SPACE 2018
September 19, 2018

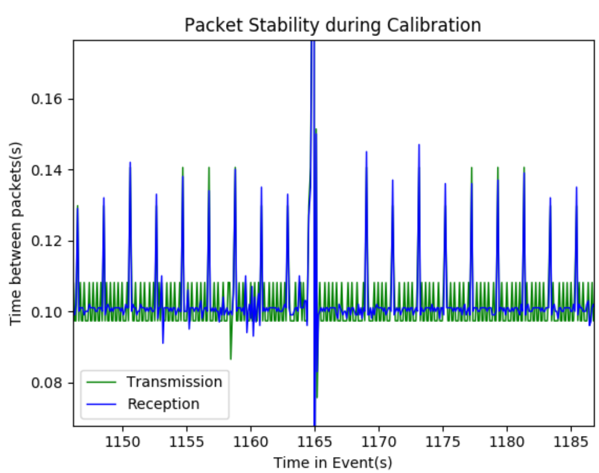
Software-driven Navigation for Station Experiment

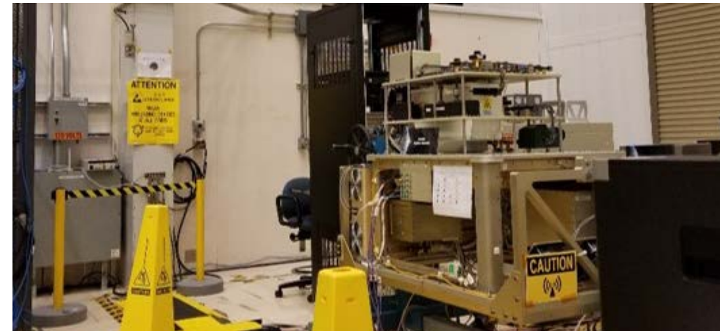
Demonstration of Software-based navigation methods for MAPS packets are transmitted to ground via ISS telemetry, direct-TDRs link and direct-to-ground from SDR Testbed. Pseudolite signals also being transmitted direct-to-ground via SDR Testbed. MAPS ground node will receive and parse direct signals while connected at GRC to local ground station antenna.

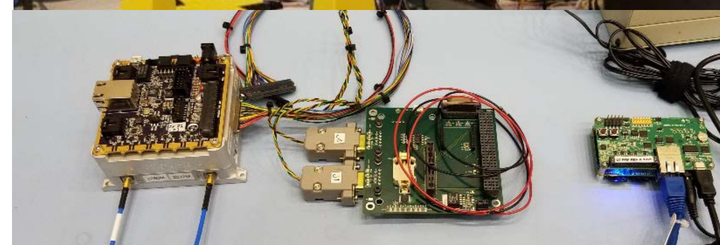


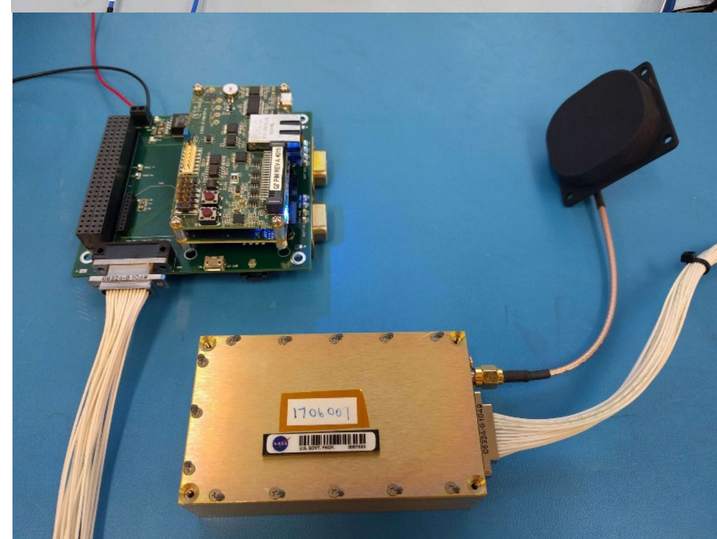
Development and Testing

- Implemented MAPS library within cFE architecture on cubesat flatsat (Linux on Xiphos Q7)
- Ported MAPS library core functions to SDR Testbed Avionics (VxWorks on PPC)
- Verification on Ground Interface Unit prior to launch
- Calibration with ground hardware for baseline timing uncertainty



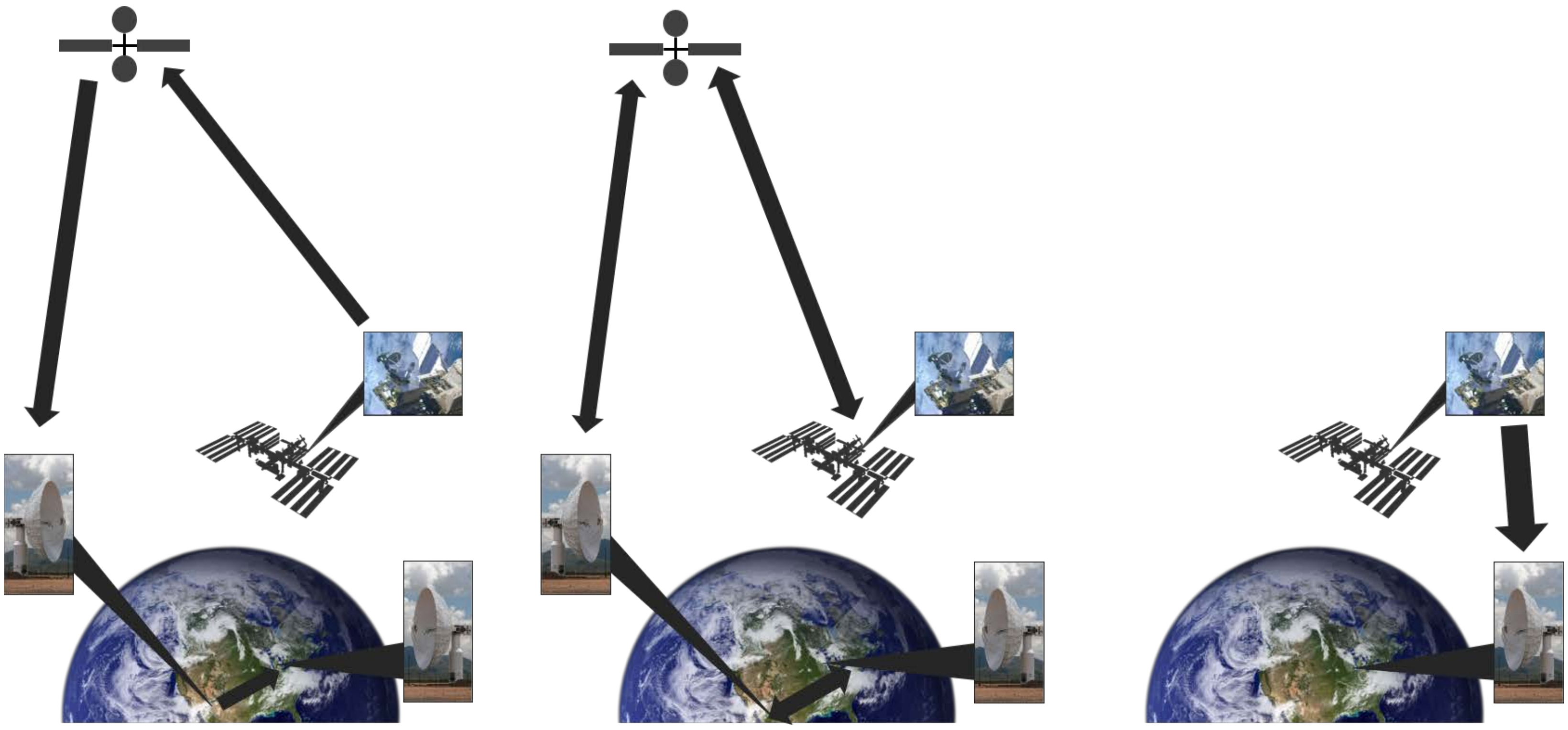






Flight Operations

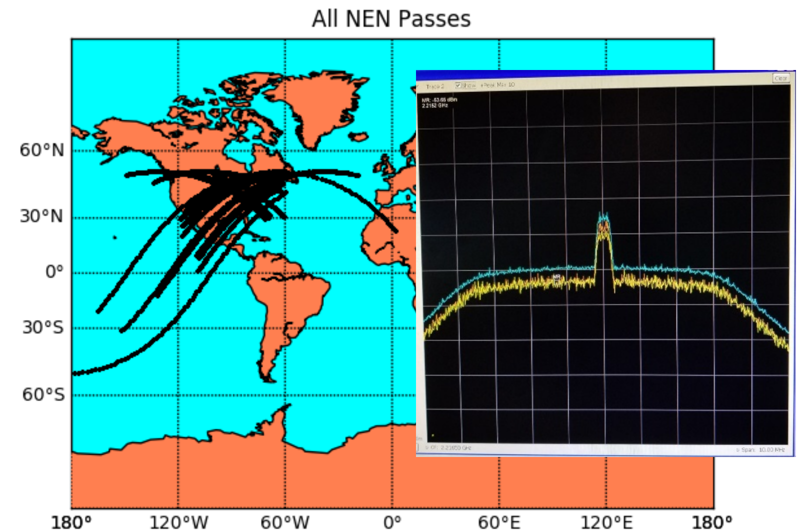
- Passes exercise variety of communication networks
- Longer baseline to TDRS for navigation performance assessment
- ISS telemetry implementation represents quickest path to integration
- Direct to ground has lowest network latency, but shortest range

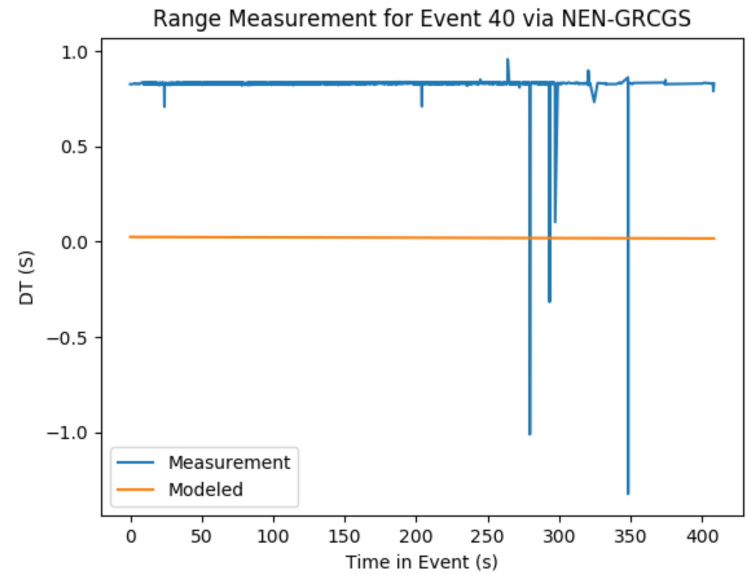


a.) b.) c.)

Direct to Ground

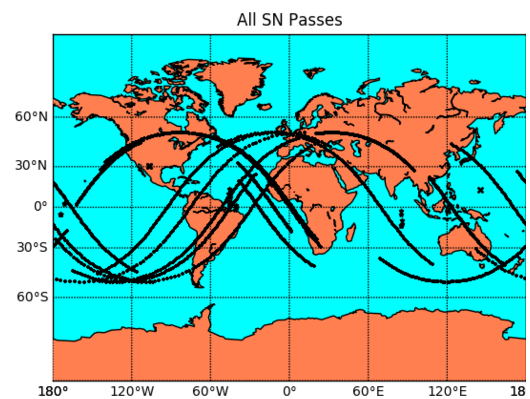
- Demonstrate ranging with minimal network latency and infrastructure
- Used NEN-compatible waveform
- Utilized ground receivers at GRC to demodulate signal and decode packets
- Packets timestamped at time of arrival
  - Raw RF also recorded for later processing/integration
- See significant latency in clocks between onboard and ground
  - Limitation of onboard clock synchronization process and inter-hardware timing
  - Using truth data to calibrate truth latency and capture performance due to in-run stability

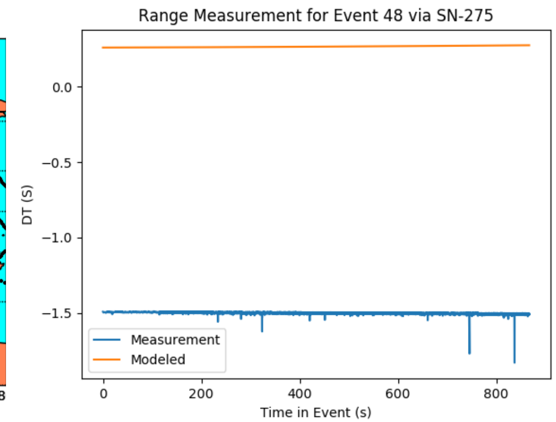


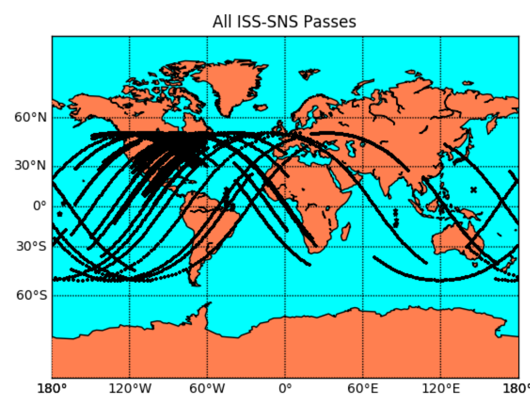


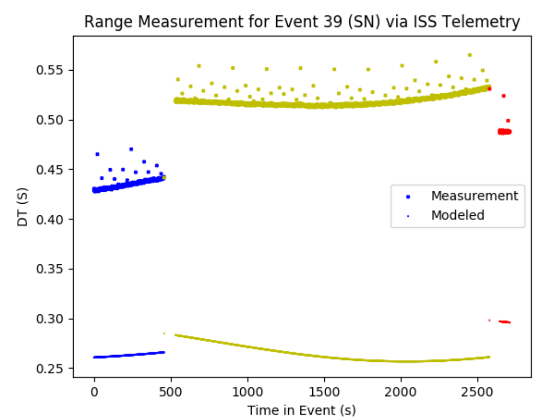
Extended Baseline Navigation

- Transmissions through TDRS and ISS telemetry paths
- Longer baseline due to high TDRS altitude
- During direct TDRS passes, ISS often provided its telemetry over multiple TDRS elements independently
- See varying latency between TDRS satellites
  - dependent on ground station infrastructure
  - Mostly stable signal but with some outliers
- Assessing latency per satellites per pass



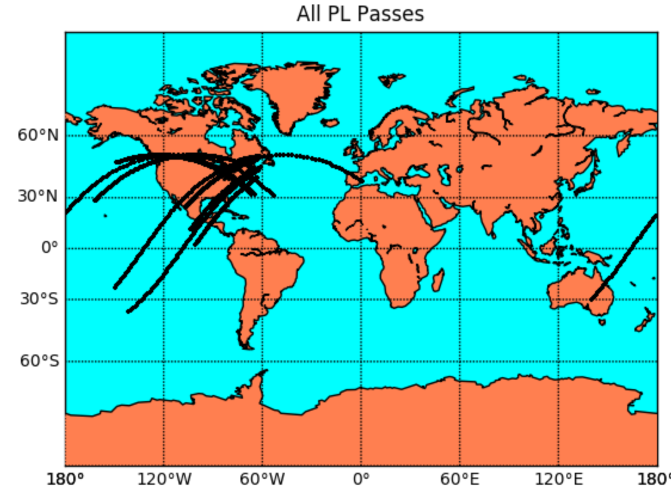


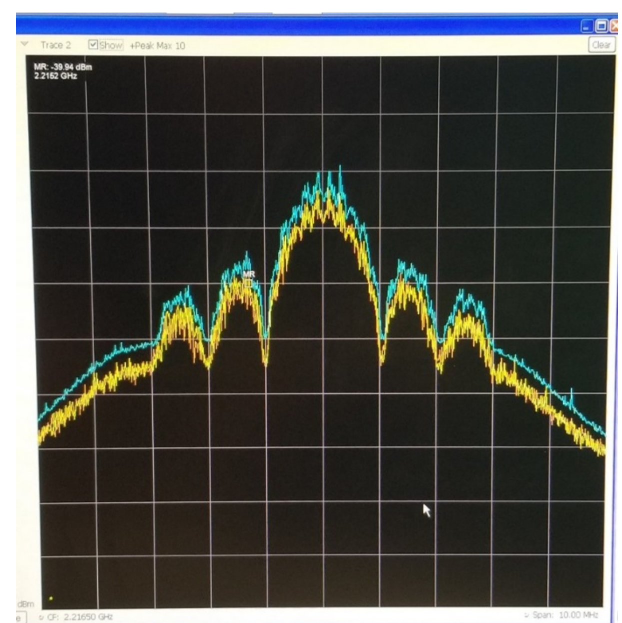




Pseudolite Demonstration

- Waveform implemented by GRC for S-band transmission
- Used PRN 35 to initialize Gold Code
- Synchronization command to sync phase to start of onboard second
- Recorded raw RF for all phases using ground SDR
- Was able to achieve lock during events
- Continuing to develop receiver to process raw measurements
- Forward efforts to implement embeddable signal transmitter and receiver



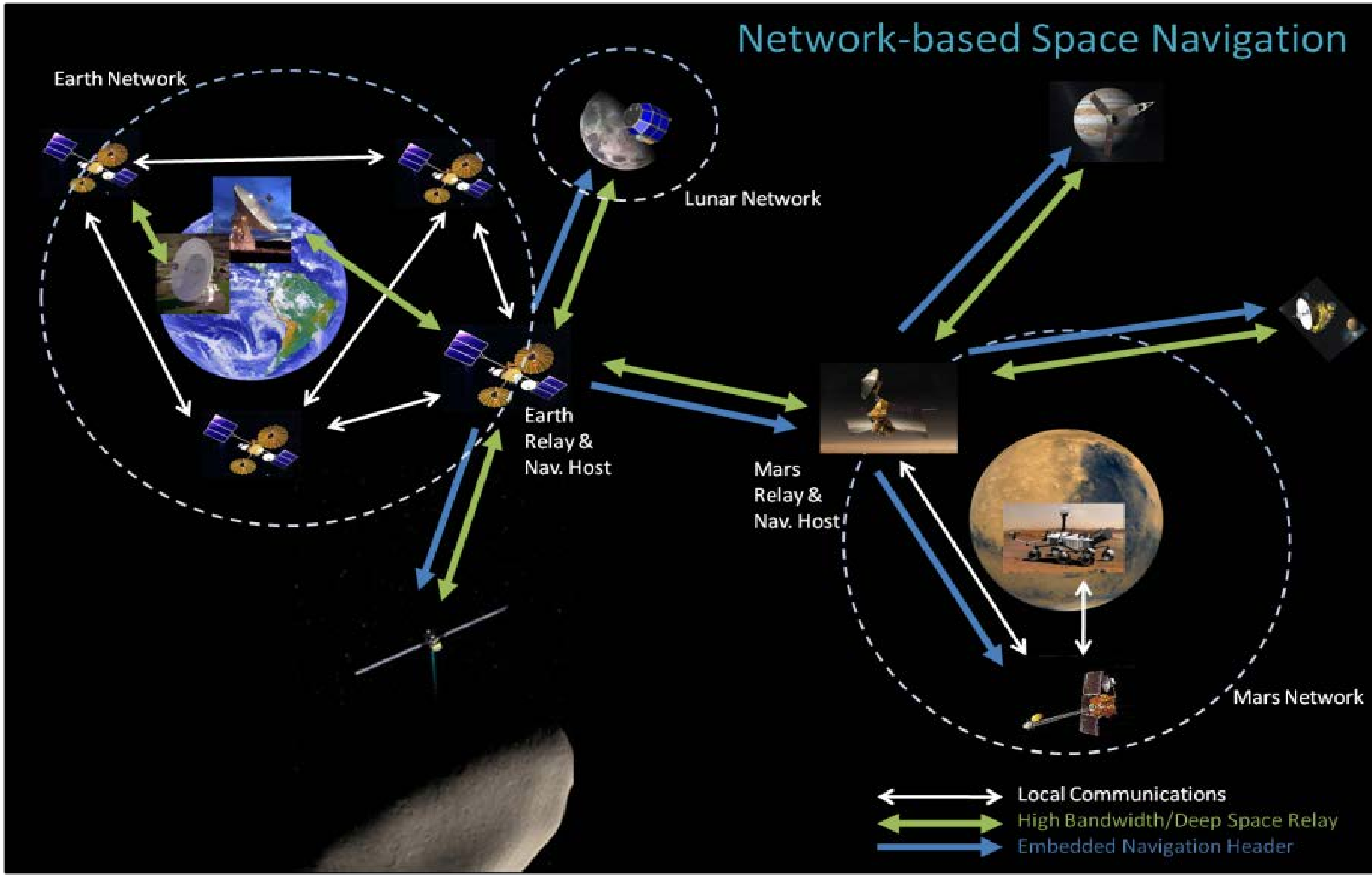


Summary and Future Work

- Captured over 12 hours of observations
- Demonstrated MAPS software integrated into orbital platform
- Next Steps:
  - Continue to evaluate navigation capability
  - Integrate with post-processed “truth” data
  - Implement calibration processing
  - Test navigation algorithms on received data
  - Mimic test setup in HWIL to continue to run hardware testing
  - Complete ground-based PL transmitter and receiver for continued testing

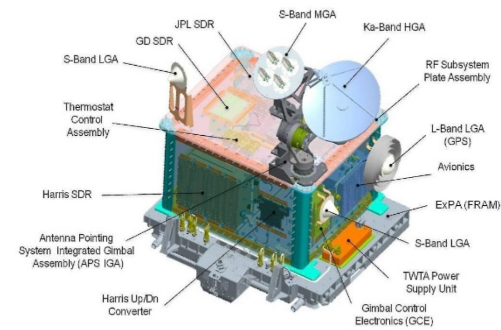
Type	Number	Max Duration (HH:MM:SS)	Mean Duration (HH:MM:SS)	Integrated Duration (HH:MM:SS)
SN	22	00:41:30	00:23:13	08:30:39
NEN	23	00:07:46	00:07:08	02:44:36
PL	11	00:08:00	00:07:09	01:18:31
All	56			12:33:46

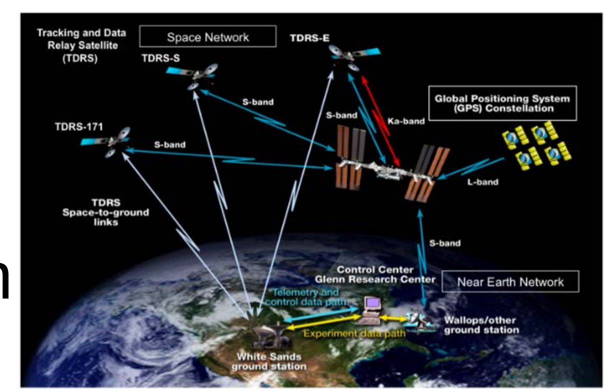
From First MAPS Node Onward



SCaN Testbed (GRC)

- Platform developed and operated by SCaN out of Glenn Research Center
- Incorporates multiple SDR elements
  - L-band, S-Band, KA-band
- Broad experimenter platform
  - High bandwidth encoding algorithms
  - Ka-band checkouts with TDRS
  - GNSS software receiver testing
  - Cognitive Networking
- Dedicated Experimenter Interface software layer
- Ground and development units accessible for testing and integration





Multi-spacecraft Autonomous Positioning System

Embedding navigation headers into communication packets works with existing infrastructure, tailored to match onboard capability, and provides expanding navigation network.

- Inspirations and Basis:
  - Increased use of data relays in inter-spacecraft communications (i.e. MRO/MAVEN)
  - Use of Delay and Disruption Tolerant Networking principles to improve communication efficiency
  - Utilization of onboard state propagation models and state estimation algorithms to track current position
- New Element:
  - Embed navigation headers in communication packets into frequent inter-spacecraft links as part of evolving data network
- Enables:
  - Autonomous onboard Earth-independent navigation capabilities
  - Reduces dependence on Earth-based assets
  - Frees resources on taxed systems (i.e. DSN)
  - Improves state estimation capability with expanding network and increased spacecraft participation