A Small Satellite Lunar Communications and Navigation System

Cooperative Agreement (CA) Partnerships with Universities and NASA Centers
80NSSC20M0088

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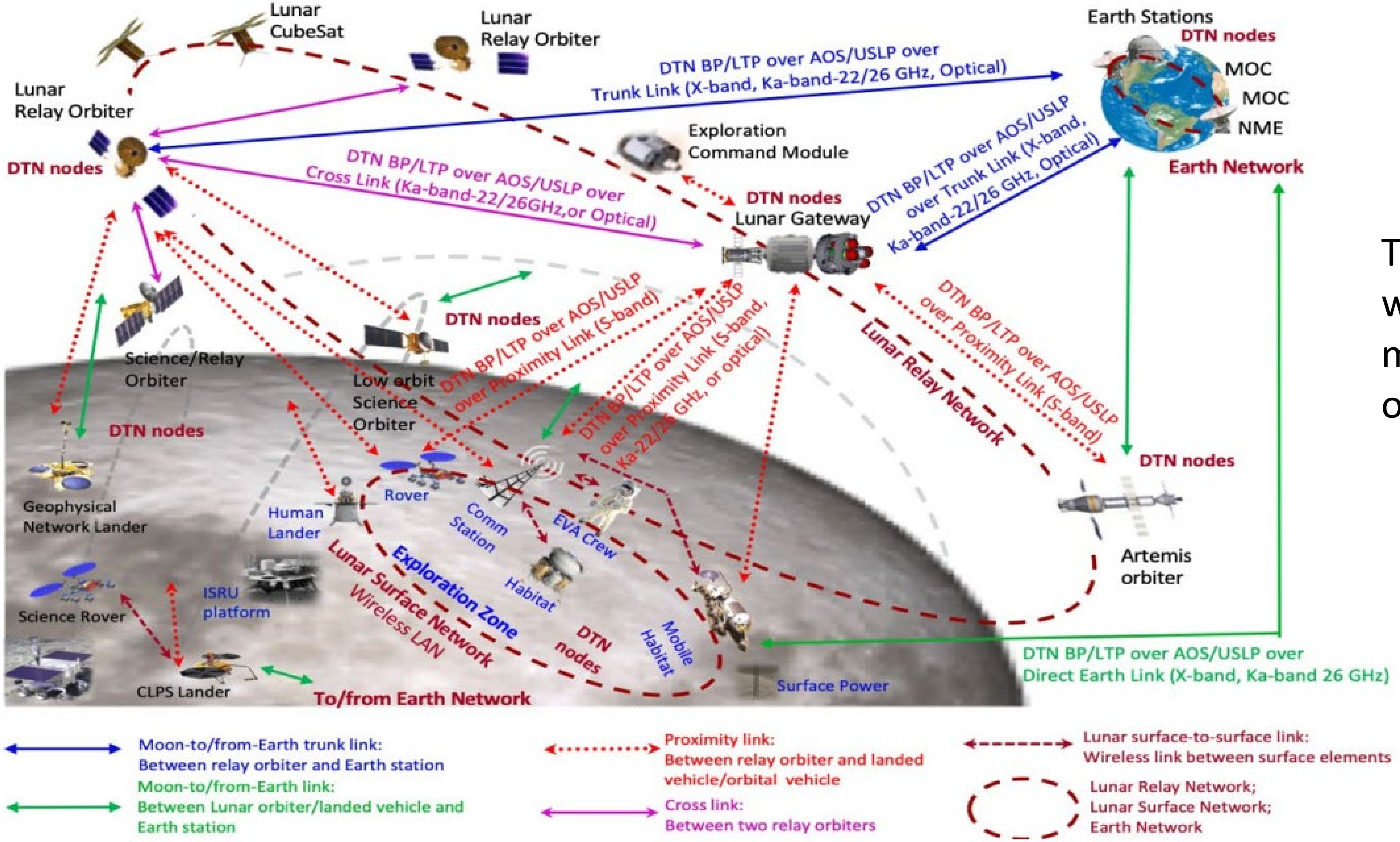
NASA LunaNet vision

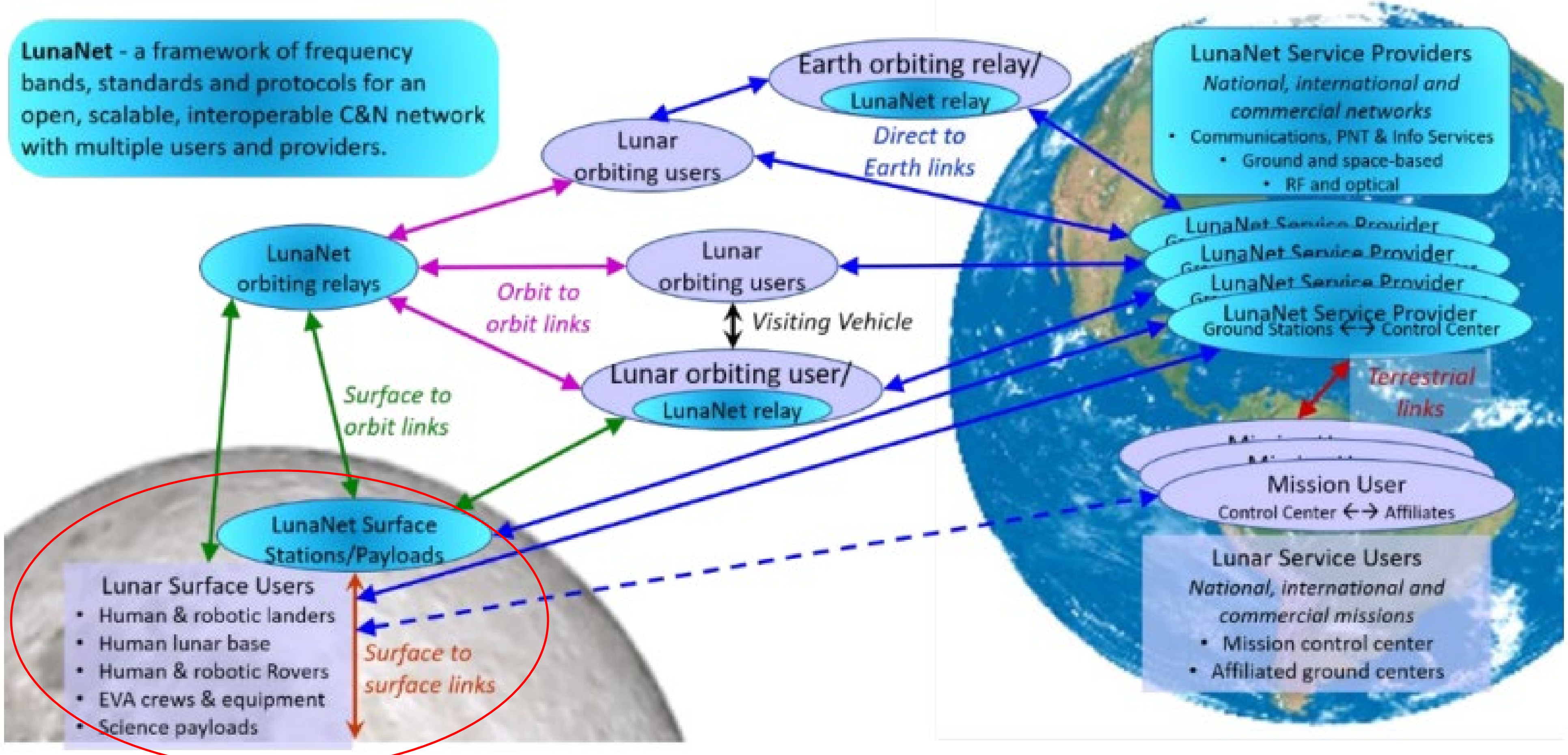


Taken from "LunaNet Architecture and Concept of Operations", SpaceOps 2021

The LunaNet architecture will provide services to missions in lunar orbit and on the lunar surface.

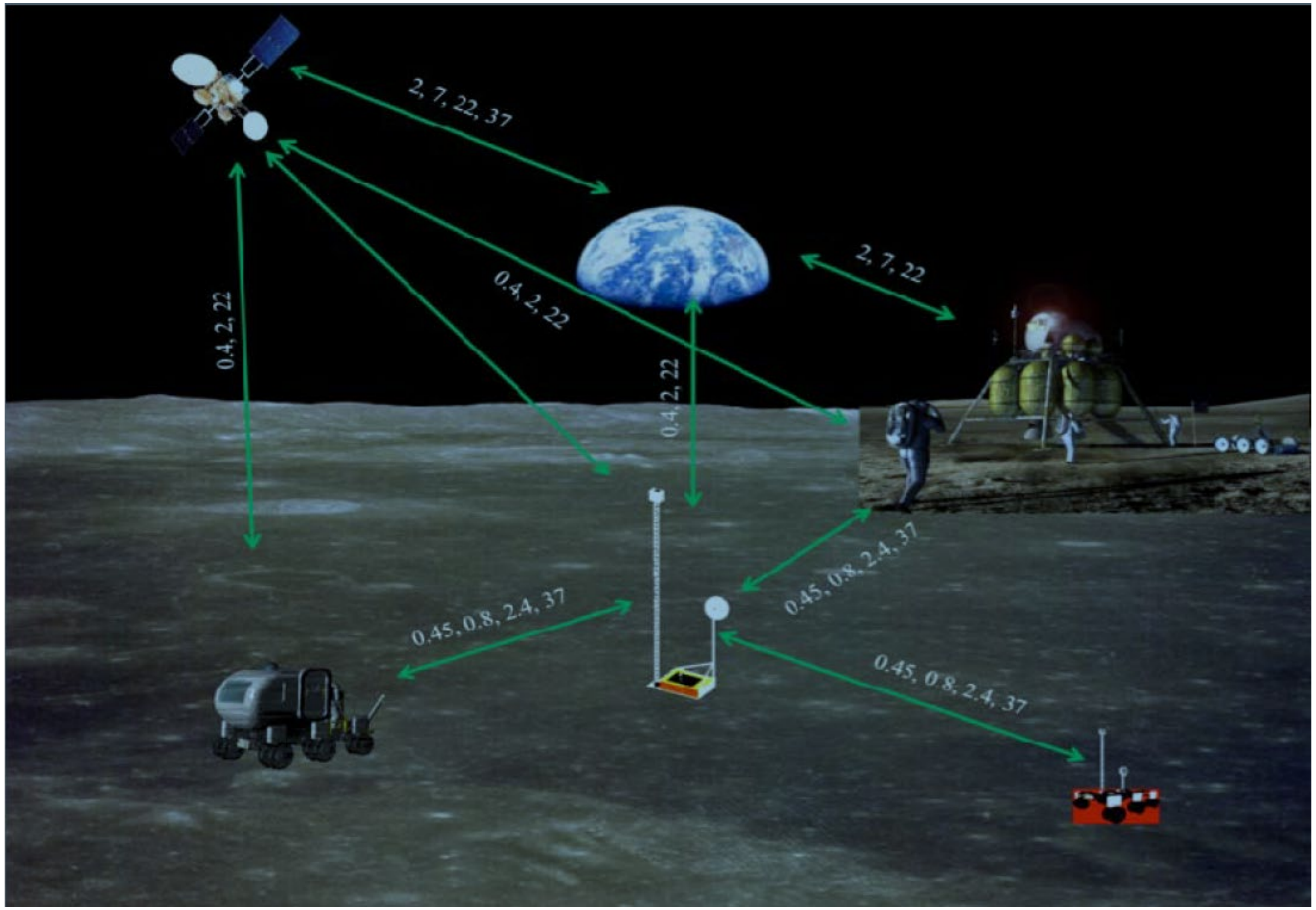
LunaNet support links

Our focus is on lunar surface users in the Aiken Basin Region



Taken from "LunaNet Architecture and Concept of Operations", SpaceOps 2021

Constraints



Shielded Zone of the Moon (SZM)

Rec. ITU-R RA.479-5

RECOMMENDATION ITU-R RA.479-5*, **

Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon

a) that Resolution B16 of the 1994 XXIIth General Assembly of the International Astronomical Union (IAU) (see Annex 2) recommends that, once radio astronomy observations in the Shielded Zone of the Moon (SZM) commence, radiocommunication transmissions in the SZM be limited to the 2-3 GHz band, but that an alternate band at least 1 GHz wide be identified for future operations on a time-coordinated basis between radio astronomy and lunar communication systems;

Radiocommunications limited to the 2-3GHz band in the SZM

A lunar PNT system should be limited to the 2-3GHz band

Original Plan

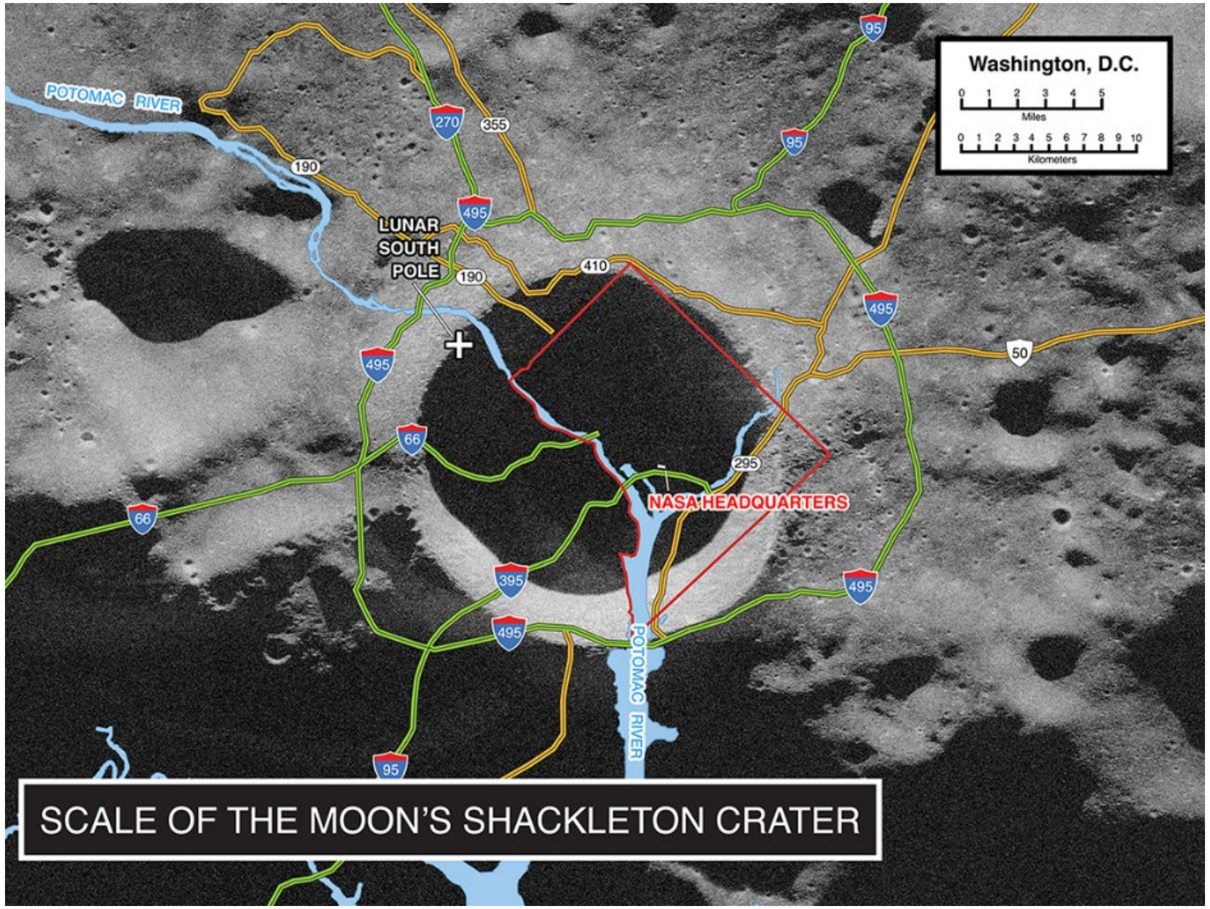
Pivot to 2.48GHz

Frequency Band	Link Types (Allocated Services[1])	Applicable Constraints[1, 2]
390-405 MHz	• Lunar Orbit (LO) to Lunar Surface (LS)	• LO to LS communications in this band will operate on a non-interference basis (NIB) to any allocated services • Shielded Zone of the Moon (SZM) consideration may apply. See Note 5.
410-420 MHz	• LS and LO EVA Communications and Wireless Network	• Power Flux Density (PFD) limits for protection of terrestrial fixed and mobile per ITU RR. No distance limitation. [Modified at WRC-15 based on Ref. **Error! Reference source not found.**] • See Note 3
435-450 MHz	• LS to LO • LS Communications & Wireless Network	• LS to LO communications in this band will operate on a NIB to any allocated services • SZM consideration may apply. See Note 5.
1614-1626.5 MHz	• LS to LO	• LS to LO communications in this band will operate on a NIB to any allocated services • SZM consideration may apply. See Note 5.
2025-2110 MHz	• Earth to LO (SRS Earth-to-space [E-s]) • Earth to LS (SRS E-s) • LO to LS (SOS space-to-space [s-s])	• For Non-Geostationary Orbit (NGSO) satellites, TT&C limited to science missions • s-s PSD per CCSDS recommendations to reduce potential Radio Frequency Interference (RFI) to E-s links • transmission masks when used in s-s direction with 2200-2290 MHz • Use for manned emergency comm (uplink or through Data Relay Satellites, DRS) • Maximum channel Bandwidth (BW) of 5 MHz • See Note 4
2200-2290 MHz	• LO to Earth (SRS space-to-Earth [s-E]) • LS to Earth (SRS s-E) • LS to LO (SOS s-s)	• For NGSO satellites, TT&C limited to science missions • s-s Power Spectral Density (PSD) per CCSDS recommendations to reduce potential RFI to s-E links • transmission masks based on necessary bandwidth and modulation • Maximum channel BW of 5 MHz • Protection of deep space operation per Ref. **Error! Reference source not found.**
2290-2300 MHz	• s-E or s-s	• Manned spacecraft emergency use, excluding 2293-2297 MHz (Ref. **Error! Reference source not found.** protection required within 2293-2297 MHz) • See Note 4
2400-2480 MHz	• LS Communications & Wireless Network	• Lunar surface communications and wireless networks in this band will operate on a NIB to any allocated services • SZM consideration may apply. See Note 5.

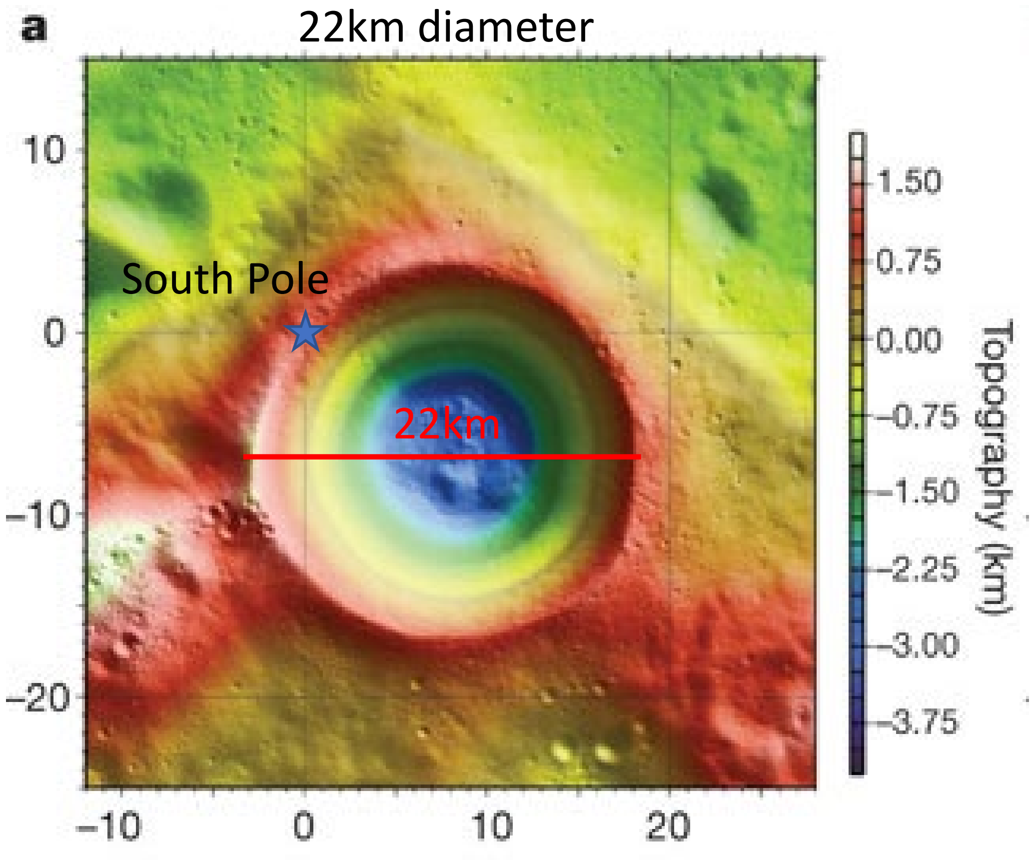
GSFC LunaNet : Key Findings

1. This architecture directly supports the agency's Moon to Mars Artemis Program.
2. A networking architecture enables commercial, interagency, and international partnerships and opportunities as seen in the terrestrial Internet.
3. A disruption tolerant networking (DTN) architecture allows for the build-up of the infrastructure in a phased approach that does not require continuous end-to-end connectivity for all users.
4. A DTN-based network architecture will fully translate for use at Mars when the speed of light delays to Earth are much greater than those between the Moon and Earth.
5. Aggregating data to minimize the number of simultaneous links required between the Moon and Earth will maximize bandwidth efficiency and thus stay within reasonable costs of the Earth ground station systems (It is unreasonable to assume an >18m antenna for every SmallSat in view from Earth, for example).
6. LunaNet is an instantiation of the Space Mobile Network framework, fully consistent with NASA SCaN architecture and the currently defined International Lunar Communications Architecture.
7. Position, Navigation, and Timing (PNT) and Science Utilization Services including Space Weather (SpWx) are critical to lunar space and surface users as well as astronaut safety.
8. The LunaNet architecture fosters the establishment of commercially sourced supply chain for components, subsystems, services, and other needs.

The lunar South Pole's Shackleton Crater



Taken from “NASA’s Plan for a Sustained Lunar Exploration and Development”



Rim to crater bottom ~4km

Our Goals

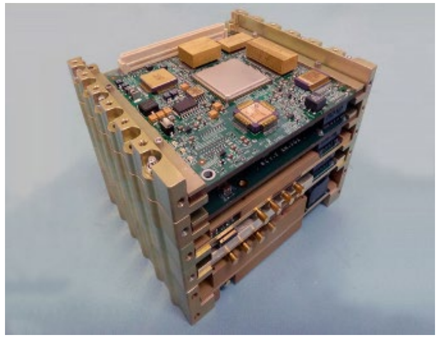
- Support early science instruments and exploration in the Aiken Basin region
- Scalable approach consistent with LunaNet architecture
- Use small sat and COTS parts where possible
- Provide accurate timing information ~1usec
- Provide coarse position information ~10m
- Provide emergency SMS service
- Provide broadcast “Amber Alerts” regarding space weather events

Leverage Existing Hardware

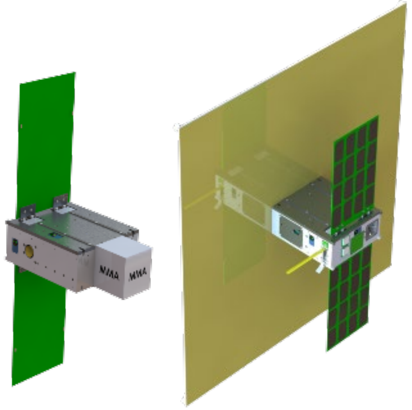
Bluefin X-band Transmitter

Chip Scale Atomic Clock

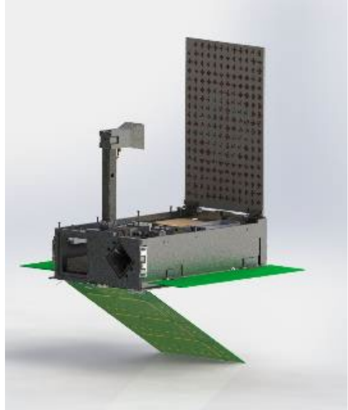
Lime SDR



JPL IRIS X, Ku-band Transponder



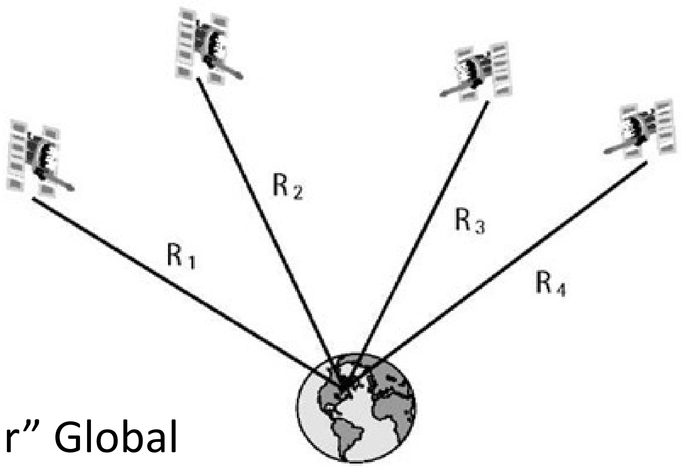
MAXWELL CubeSat



CU-E3 CubeSat

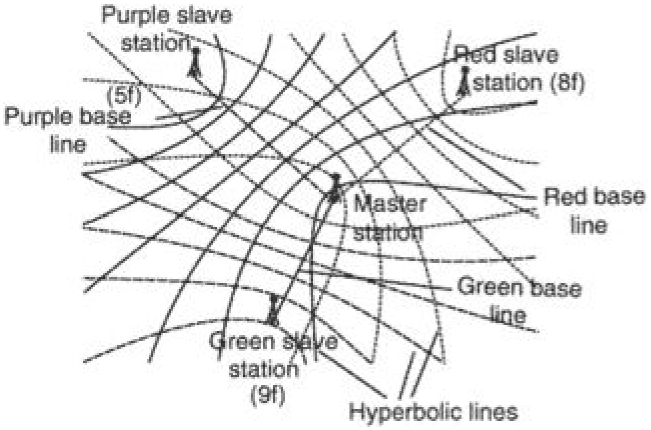
Approaches

GPS like



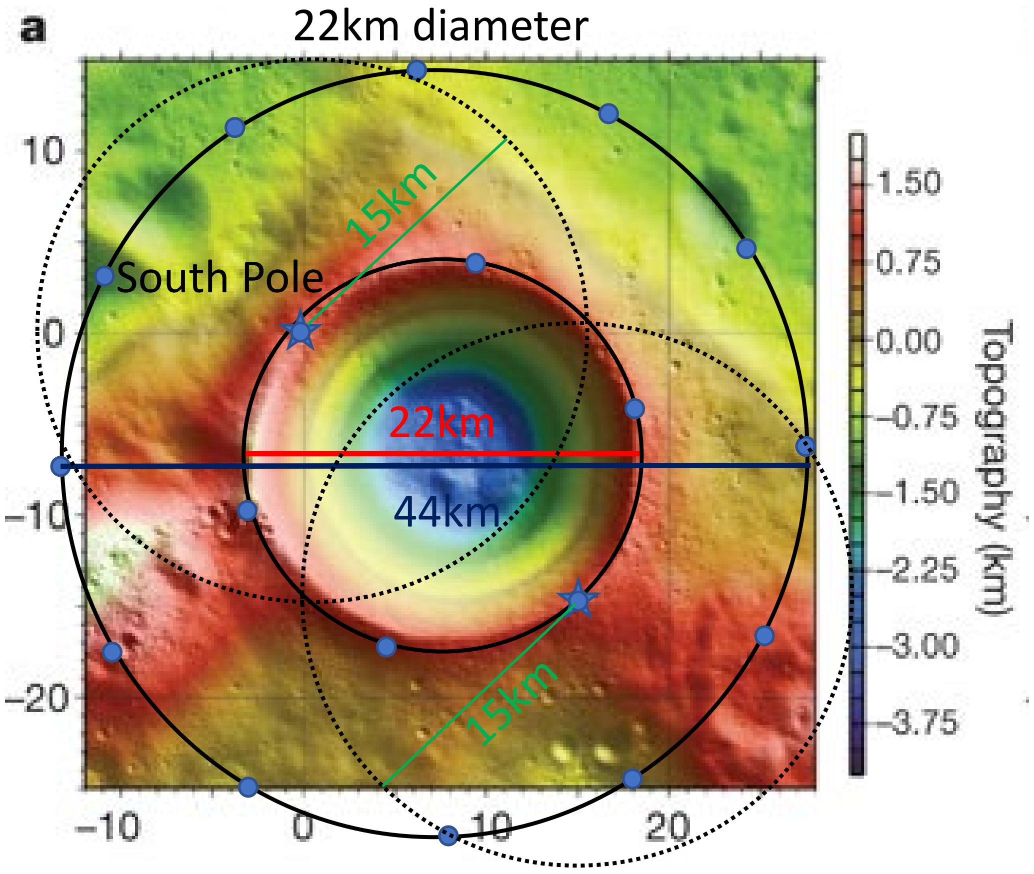
"Lunar" Global
Requires N satellites
One way ranging
Requires accurate clocks
Requires "good" geometry
UE is receive only
Does not support SMS
Lunar orbit are generally unstable

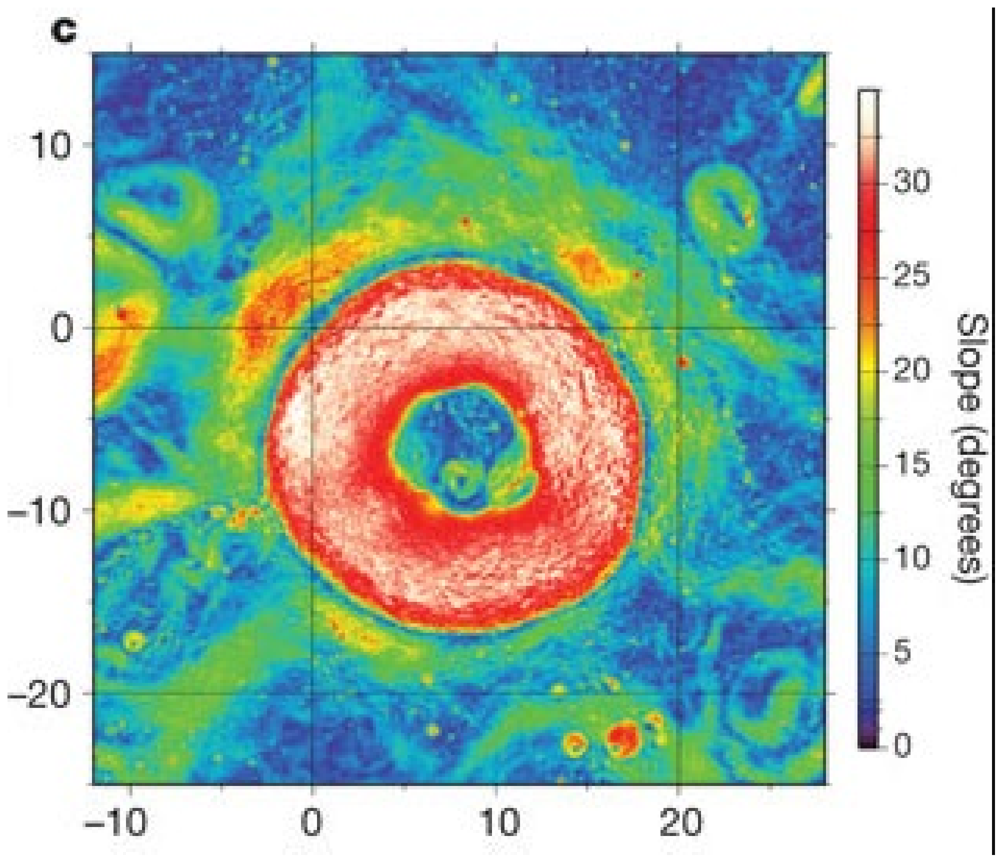
"Loran like" - Pseudolites



Can be established in regions of interest
Requires 1 satellite for time transfer
One way ranging or two way-ranging possible
Reduce dependence on accurate clocks
Requires "good" geometry
UE can be receive/transmit
Does support SMS

Pseudolite Placement



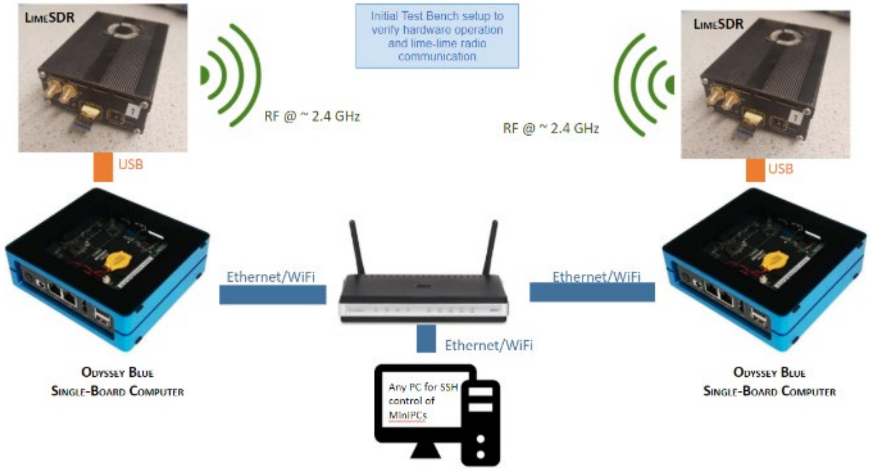


Geometric Configuration

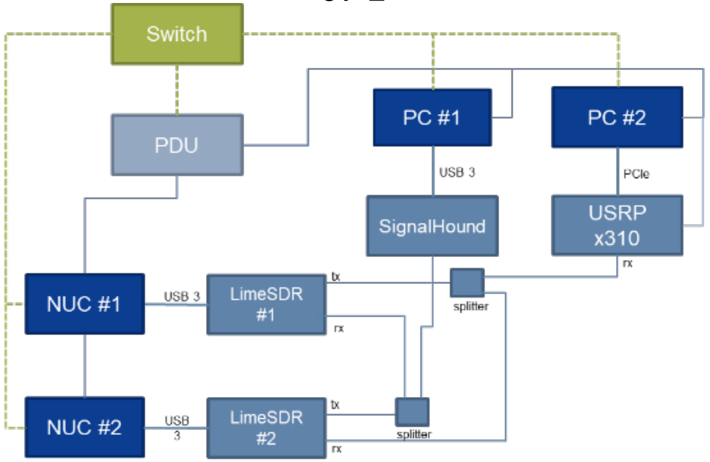
1. One ring of 6 units on rim of Shackleton crater (22km diameter)
   - Two stable units (Rb oscillator)
     - One at South Pole
     - One on opposite side of Shackleton crater
   - Four additional standard units (OCXO or LNCSAC)
2. Second ring of 12 units
   1. 44km ring radius centered on Shackleton crater
   2. All are standard units
3. Leverage slope of crater for increased range and support in crater operations
4. 15-20 km transmission range

Testbed Status

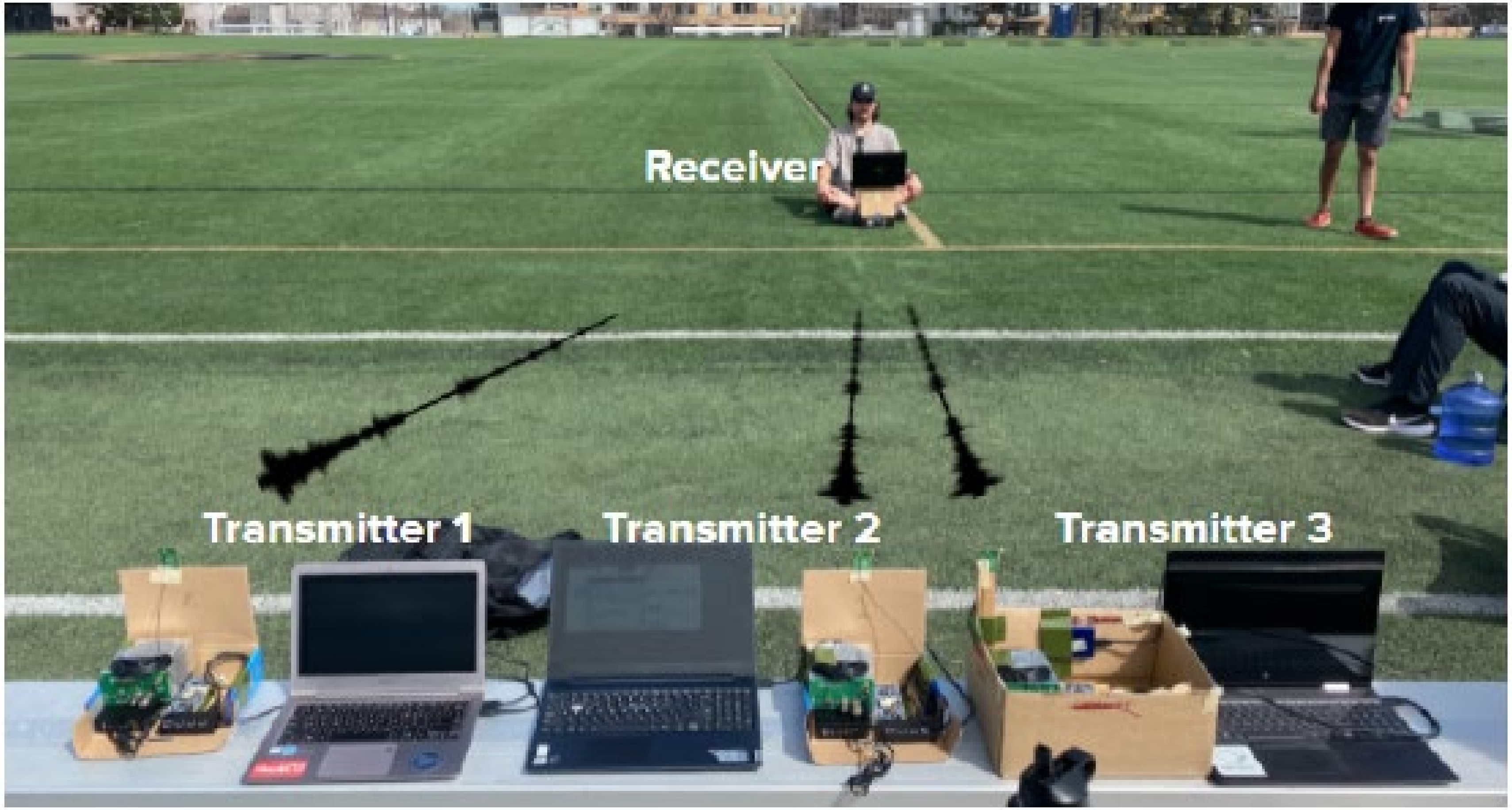
University of Colorado



JPL

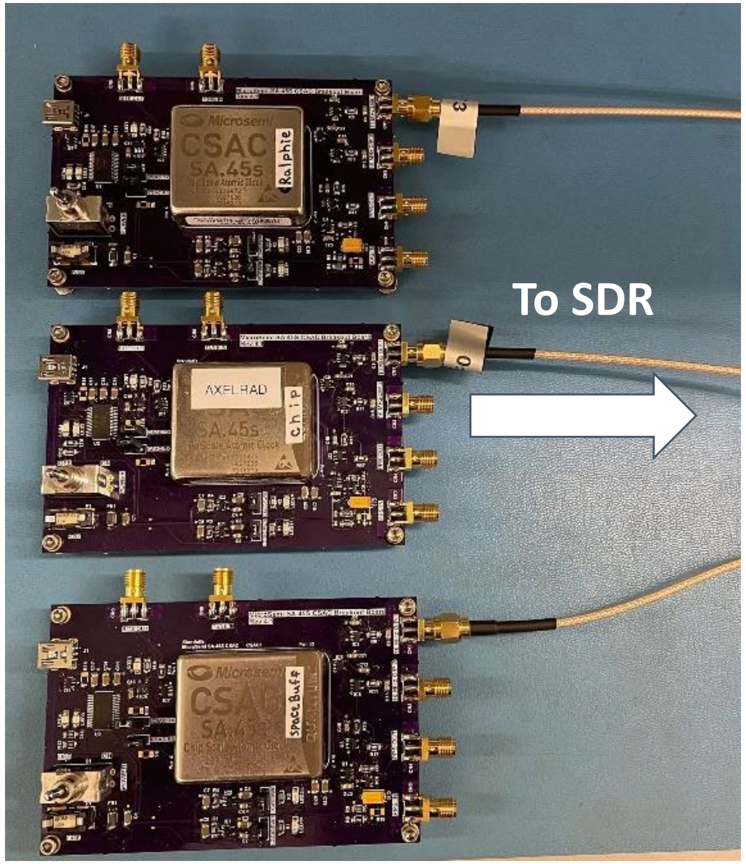


Risk Reduction Outdoor Testing



CSAC Testing

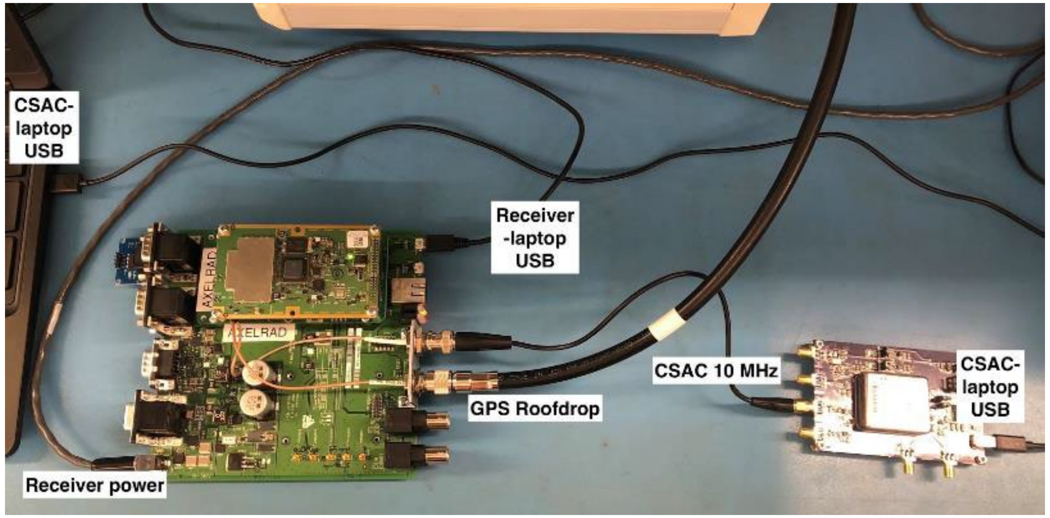
CSAC and SDR hardware for characterizing multiple clocks using an Rb reference



3 CSACs being tested on CU developed evaluation PCB

GNU Radio software used for capturing measurements and computing biases

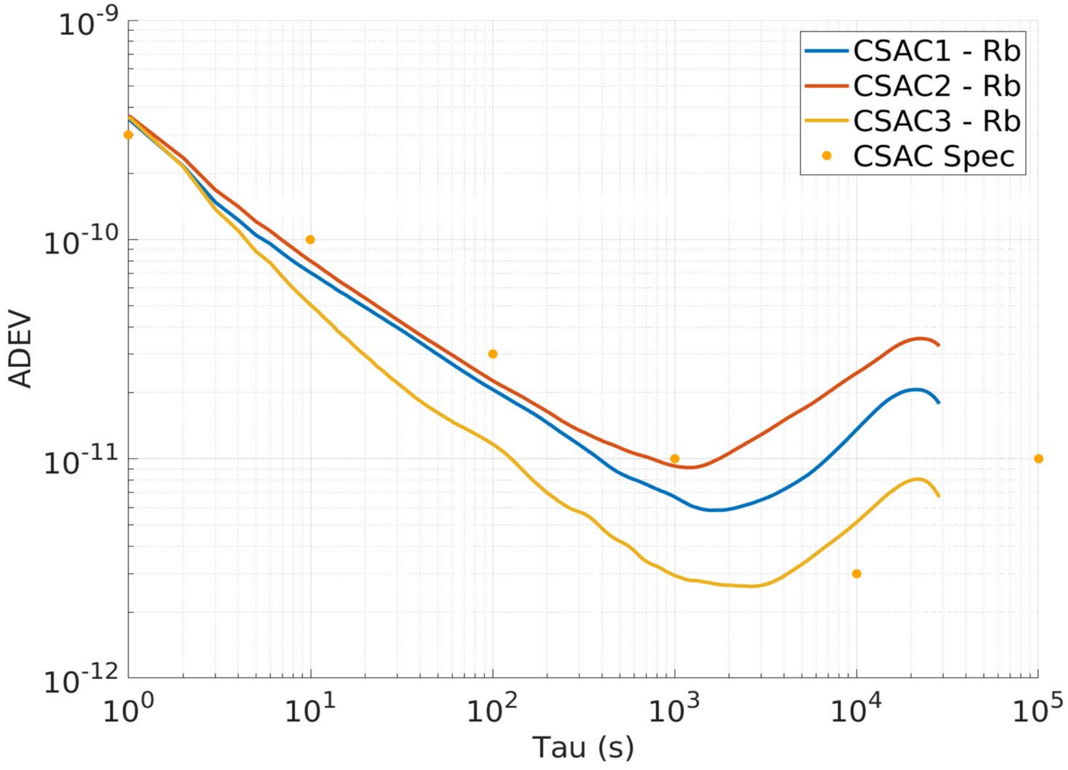
Ettus N310 SDR used for data collection



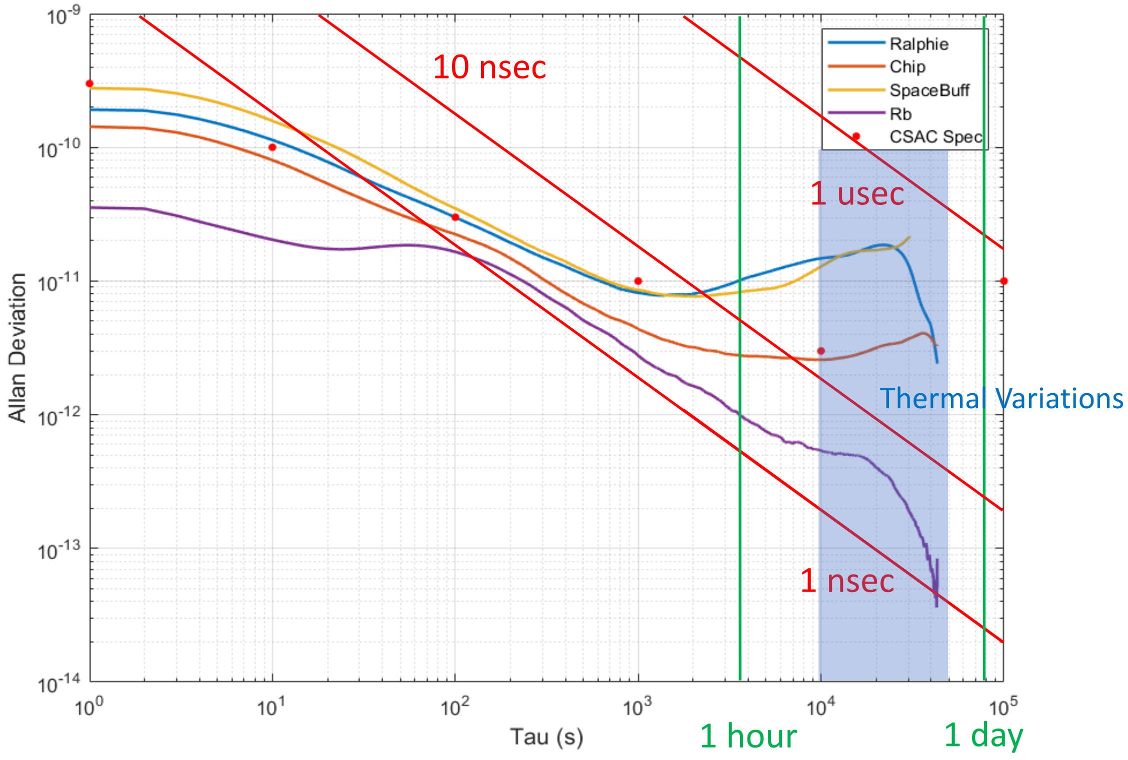
Novatel OEM 729 CSAC/GPS Testing

Oscillator Allen Deviation

CSAC testing with Rb Reference

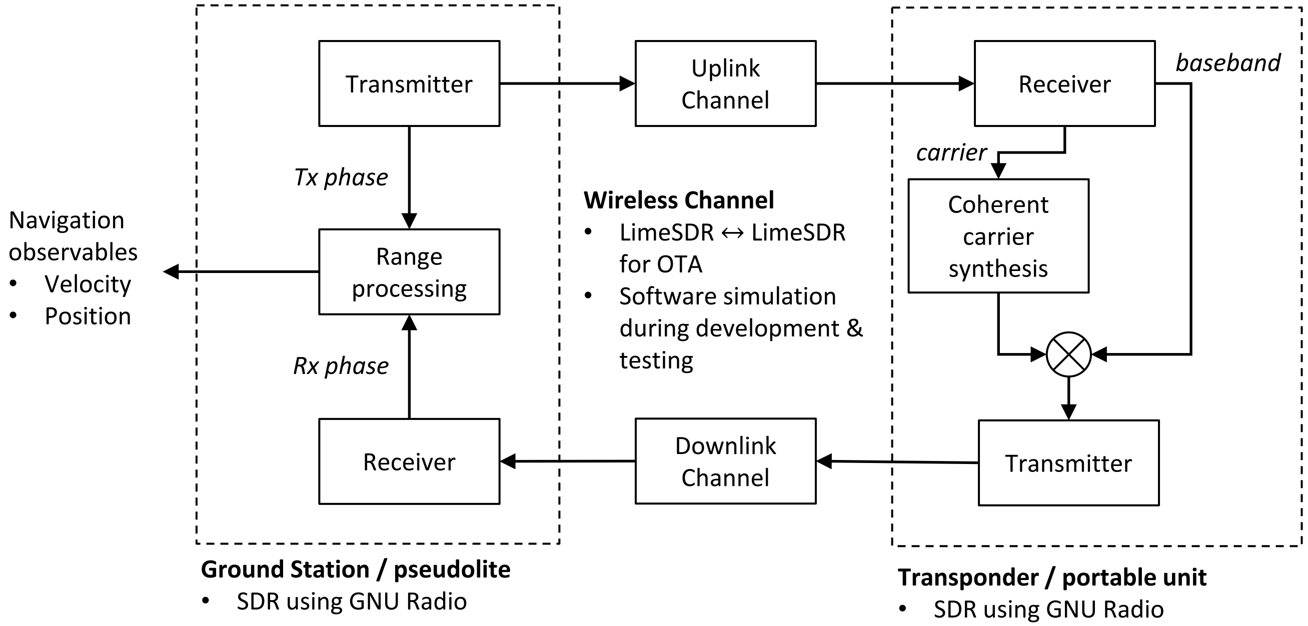


CSAC and Rb testing with GPS Reference



Ranging Status

- JPL is adapting DSN-style two-way PN ranging to the LimeSDR + GNU Radio platform.
- Early versions of the ground station and transponder flowgraphs exist and are stable. Further development is necessary

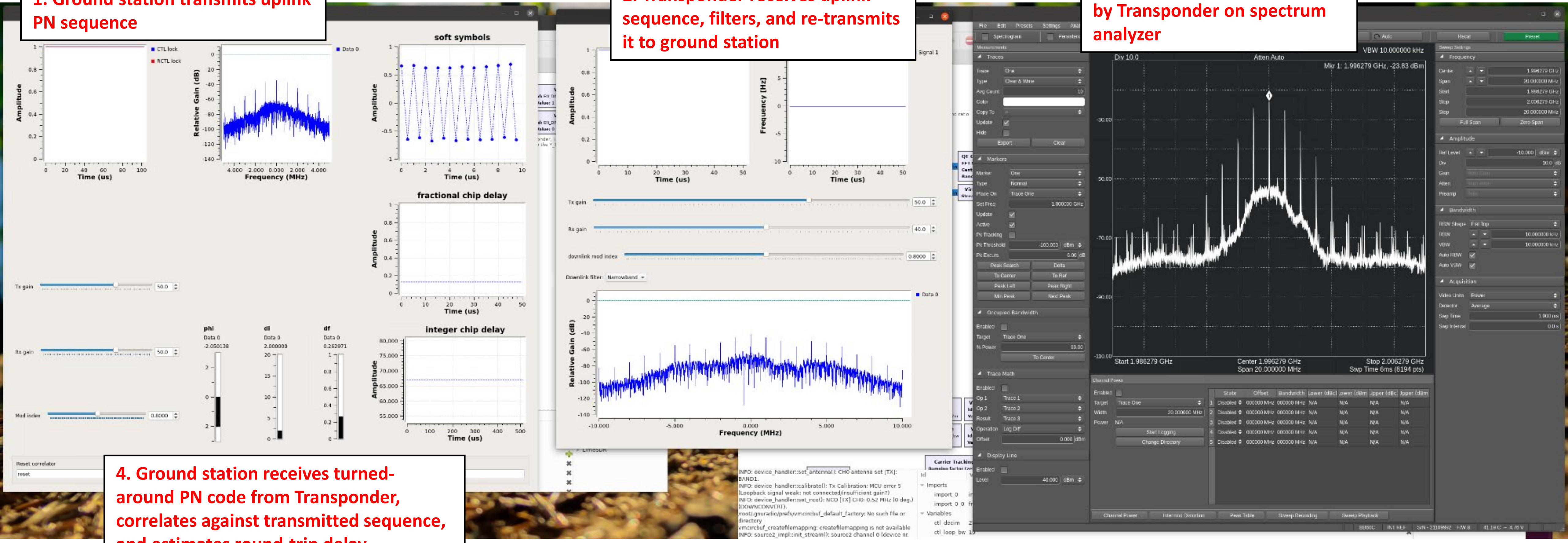


Ranging Status

1. Ground station transmits uplink PN sequence

2. Transponder receives uplink sequence, filters, and re-transmits it to ground station

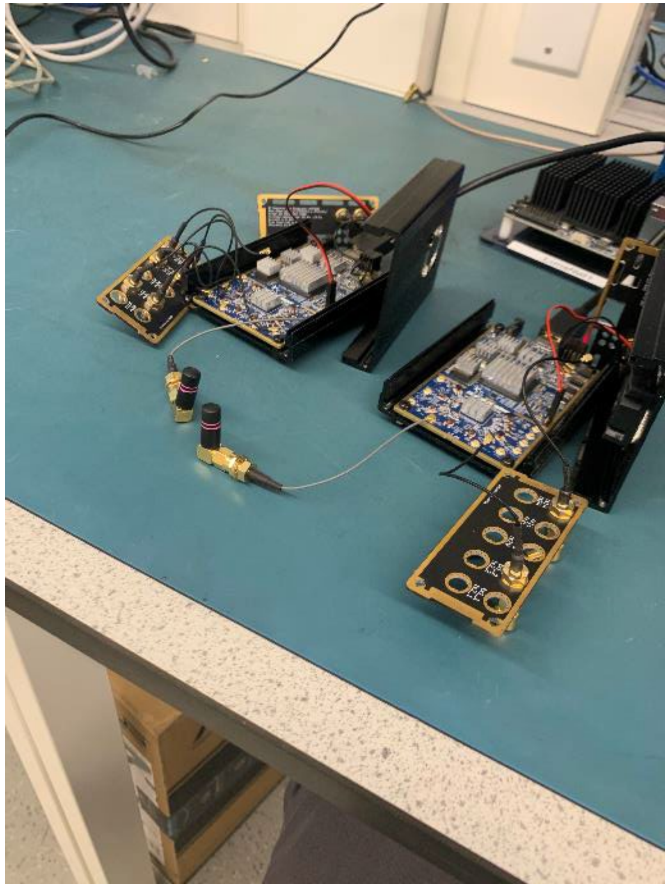
3. Downlink signal transmitted by Transponder on spectrum analyzer



4. Ground station receives turned-around PN code from Transponder, correlates against transmitted sequence, and estimates round-trip delay

Benchtop Testing Status

Test	Complete?
OFDM Communications	
OFDM Loopback	Y
OFDM Wired	Y
OFDM Wireless	Y
BPSK Communications	
BPSK Loopback	Y
BPSK Wired	Y
BPSK Wireless	Y
Code Ranging	
Code Ranging Wired	
Code Ranging Wireless	
Code Ranging Loopback	



Wireless Test Setup

Summary

- CU and JPL are co-developing a lunar PNT system
- Leveraging existing and COTS hardware
- JPL has developed ranging test-bed
- CU has developed hardware for outdoor test range
- BPSK and OFDM operational
- Initial outdoor test range expected to be operational in late 2022