# NASA's Next Generation Space Geodesy Co-located Sites

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# Outline

- Next-Generation NASA Space Geodesy Network Deployment Overview
- Co-Location Site Requirements
- Lessons Learned from Prototype Co-Location Site
- Implementation of Co-Location Site at the McDonald Observatory

# It takes a village…

**VLBI**
- Orientation of ITRF with respect to ICRF
- ITRF Scale

**SLR**
- Origin of ITRF (Earth’s CM)
- ITRF Scale
- Position spacecraft in ITRF (“Orbits”)

**GNSS**
- Precise monitoring of Polar Motion and Rotation Rate
- Position spacecraft in ITRF (“Orbits”)
- Position instruments on Land and Sea (Tide Gauges and Buoys, Geodetic Instruments)

**DORIS**
- Position spacecraft in ITRF (“Orbits”)
- Enhances global distribution of ITRF Station positions and velocities

Technique Connectivity (Station Co-Location)

Fully Define ITRF

VTS: ITRF Performance Improvement

**Origin, Scale, Orientation**

Low-Density Global Distribution

High-Density Global Distribution

# We Go Forward. Only Forward.

- The VLBI2010 Global Observing System (VGOS):
  - 1 mm measurement accuracy on global baselines,
  - Continuous measurements for time series of station positions and Earth orientation parameters,
  - Turnaround time to initial geodetic results of less than 24 hours,
  - Small, fast, efficient antennas,
  - Broadband (2-14 GHz),
  - Fast data recording rates (2-16 Gbps).
- NASA's Space Geodesy Satellite Laser Ranging (SGSLR) System:
  - 24 hour tracking of LEO, LAGEOS & GNSS satellites,
  - 1 mm normal point precision on LAGEOS,
  - Stability at the 1mm level over one hour,
  - Calibrated against the network standard,
  - kHz pulse rate laser with single photon detection system,
  - Automated operations.
- Collocated with multi-constellation GNSS stations and DORIS beacons.
- Local tie definition and monitoring at 1mm accuracy or better.

# NASA VLBI Deployment

- Based upon prototype system at Goddard.
- Meets the VGOS requirements set by the international VLBI community for a modern network.
- Salient features:
  - 1 mm accuracy on global baselines,
  - Small, fast, efficient antennas,
  - Broadband and fast data rates.
- Hawaii station installed and being commissioned.

Goddard Geophysical and Astronomical Observatory

<u>Future Sites</u>

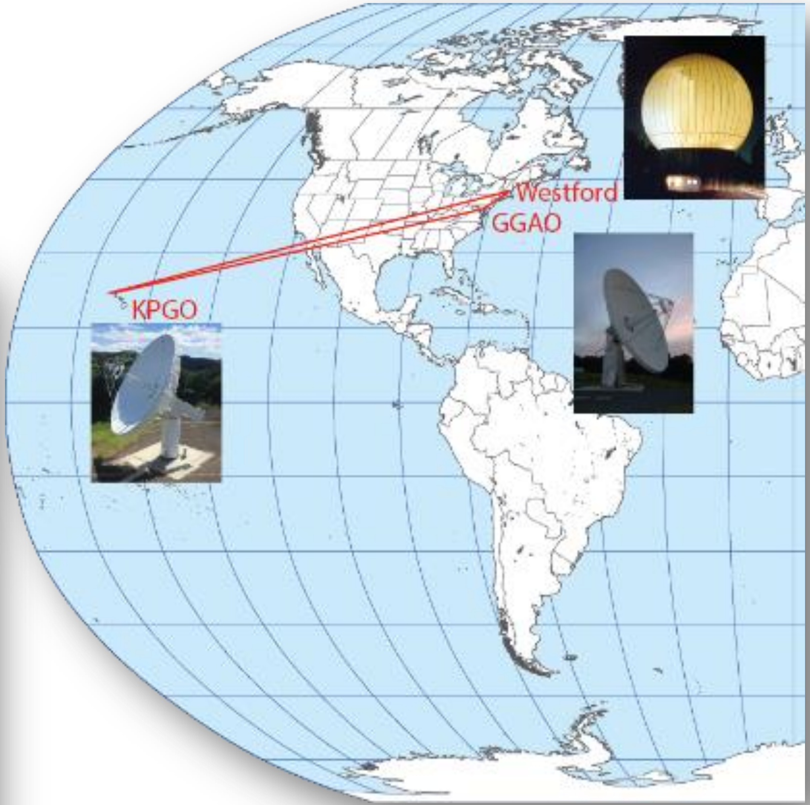
McDonald Observatory, Texas

Tahiti

Kōke‘e Park Geophysical Observatory, Hawaii

# World's First 3-Way Next Generation VLBI Measurement Using New Hawaii Station

"First light" for the new joint NASA-USNO next generation Very Long Baseline Interferometry (VLBI) station at NASA's Kōkeʻe Park Geophysical Observatory (KPGO) in Hawaii occurred on February 1, 2016.




World's first 3-way broadband VLBI measurement was made on February 5, 2016 using the antennas at KPGO, Westford in Massachusetts, and the Goddard Geophysical and Astronomical Observatory (GGAO) in Maryland demonstrates the viability of the improved technique.

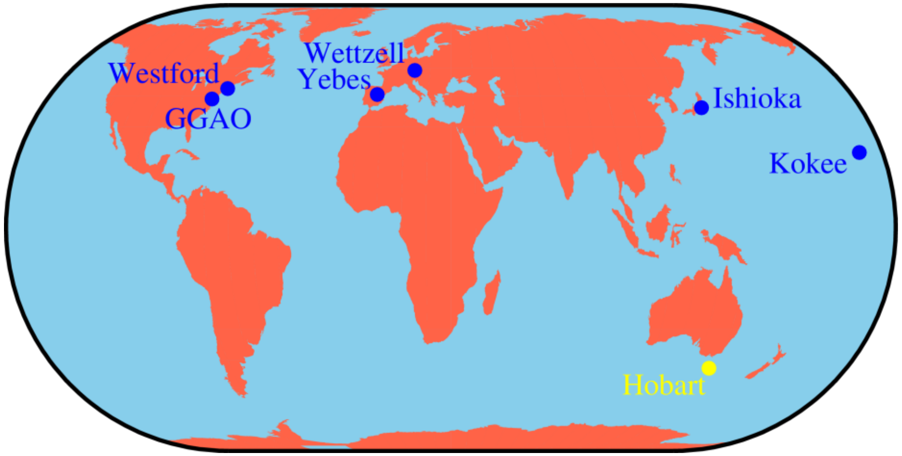
# Connecting the Old With the New

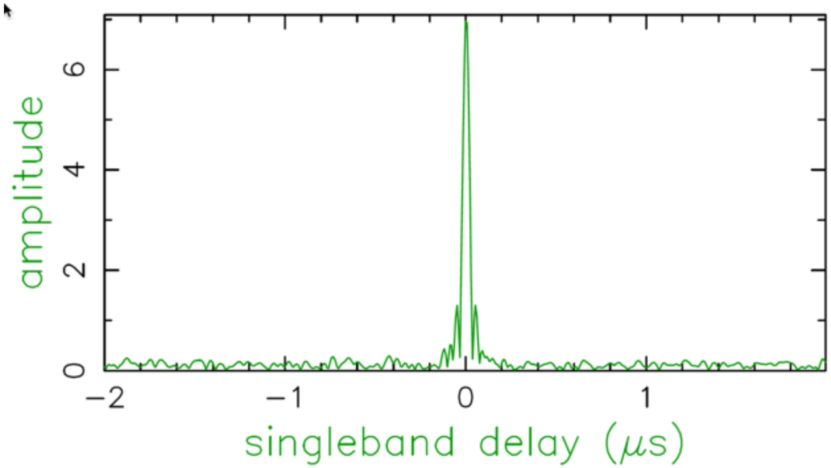
- A series of VLBI observations between the old and new USNO antennas at KPGO were taken to define the geodetic tie between the two systems before work starting on replacing the 20m main bearing.

# International VGOS Compatibility Test Sessions

## VGOS trial network and observing

- Four 24-hour test sessions to establish operational setup and procedures prior to VGOS Trial Campaign
- Start of VGOS Trial Campaign of bi-weekly 24-hour sessions using blue network on 20 September 2016
- Continuation of Trial Campaign #1 in coming weeks
- Likely repeat of Trial Campaign #1 in 2017 before moving on to daily multi-hour sessions campaigns




## Milestones

- Broadband fringes in all four bands for GGAO, Westford and Wettzell on 9 June 2016
- Verification of all four signal paths for Yebes achieved on 9 June 2016
- Broadband fringes in all four bands for GGAO, Westford and Ishioka on 25 September 2016
- Successful fringe test on three bands (single polarization) with prototype Sterling cycle cooled feed at Hobart to Ishioka (and Kashima) on 9 August 2016

# NASA SLR Deployment

- Based on NGSLR prototype at Goddard
- Salient features:
  - Day and nighttime tracking,
  - 1 mm-level range precision and stability,
  - Fast target acquisition and normal point generation.
  - Near-autonomous operations.
- Preliminary Design Review for Texas and Norway stations held April 5-6.

Goddard Geophysical and Astronomical Observatory

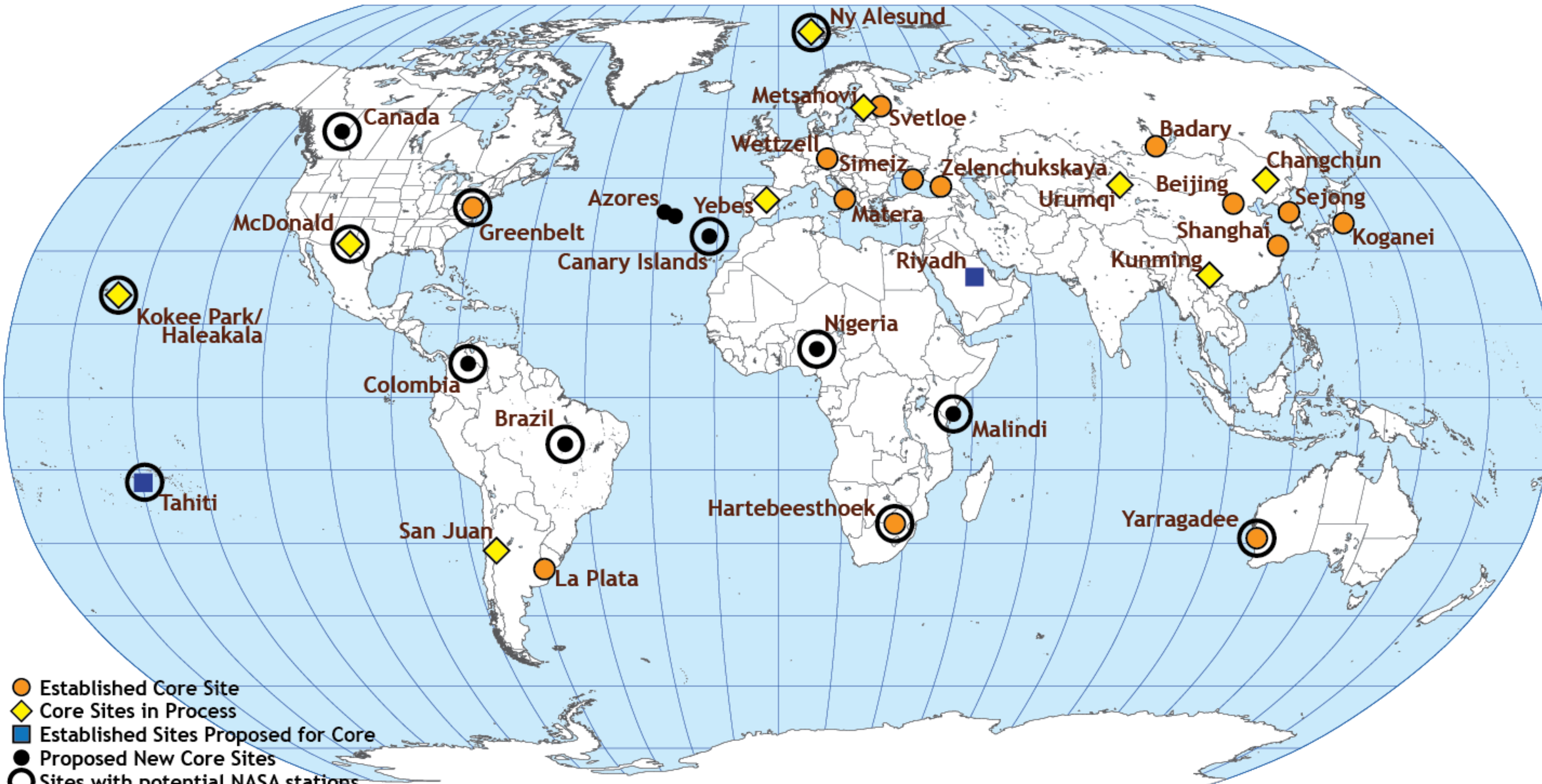
## Future Sites

McDonald Observatory, Texas

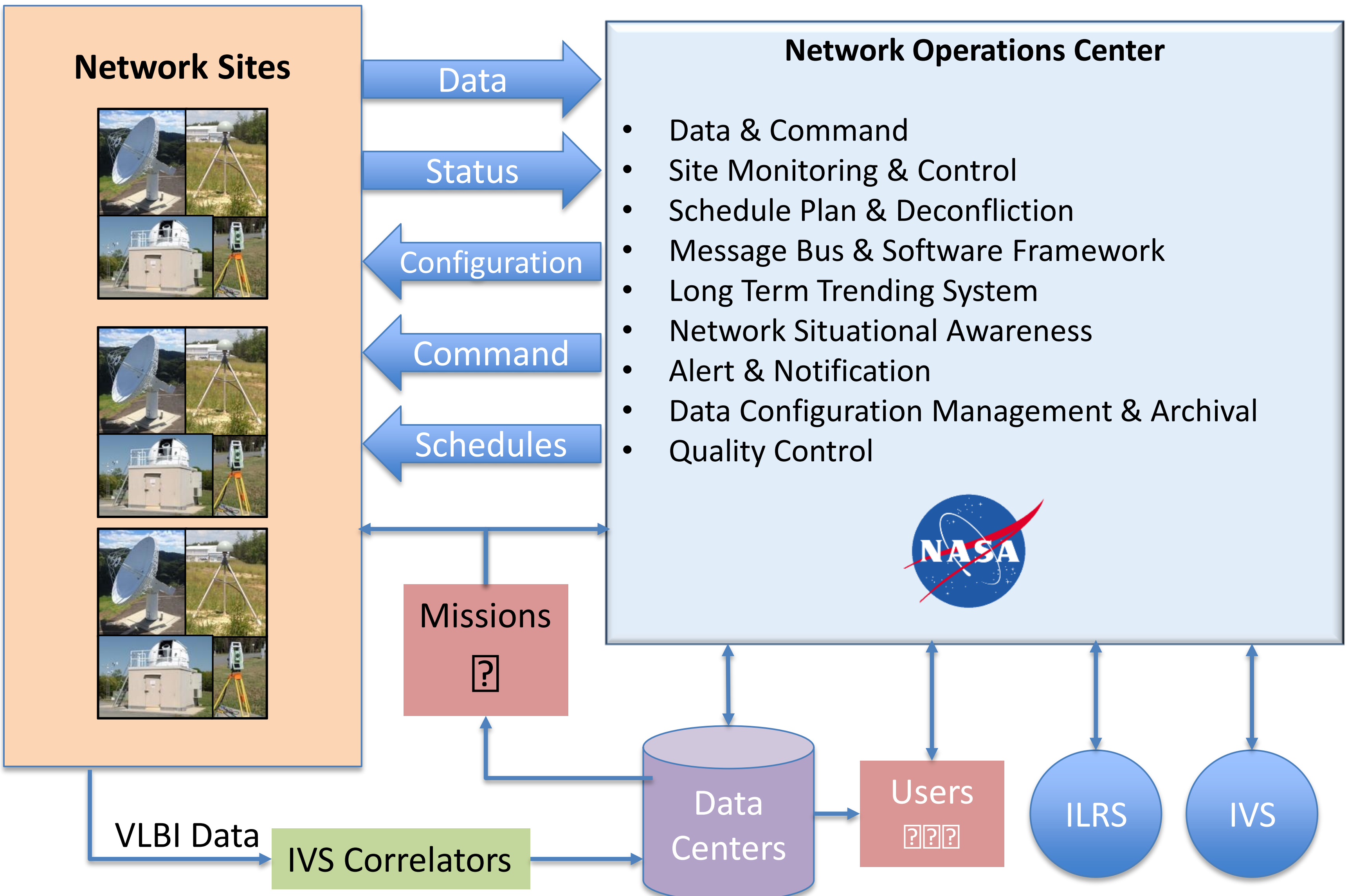
Haleakala Observatory, Hawaii

Ny Ålesund, Norway

# Current and Candidate Core Geodetic Sites



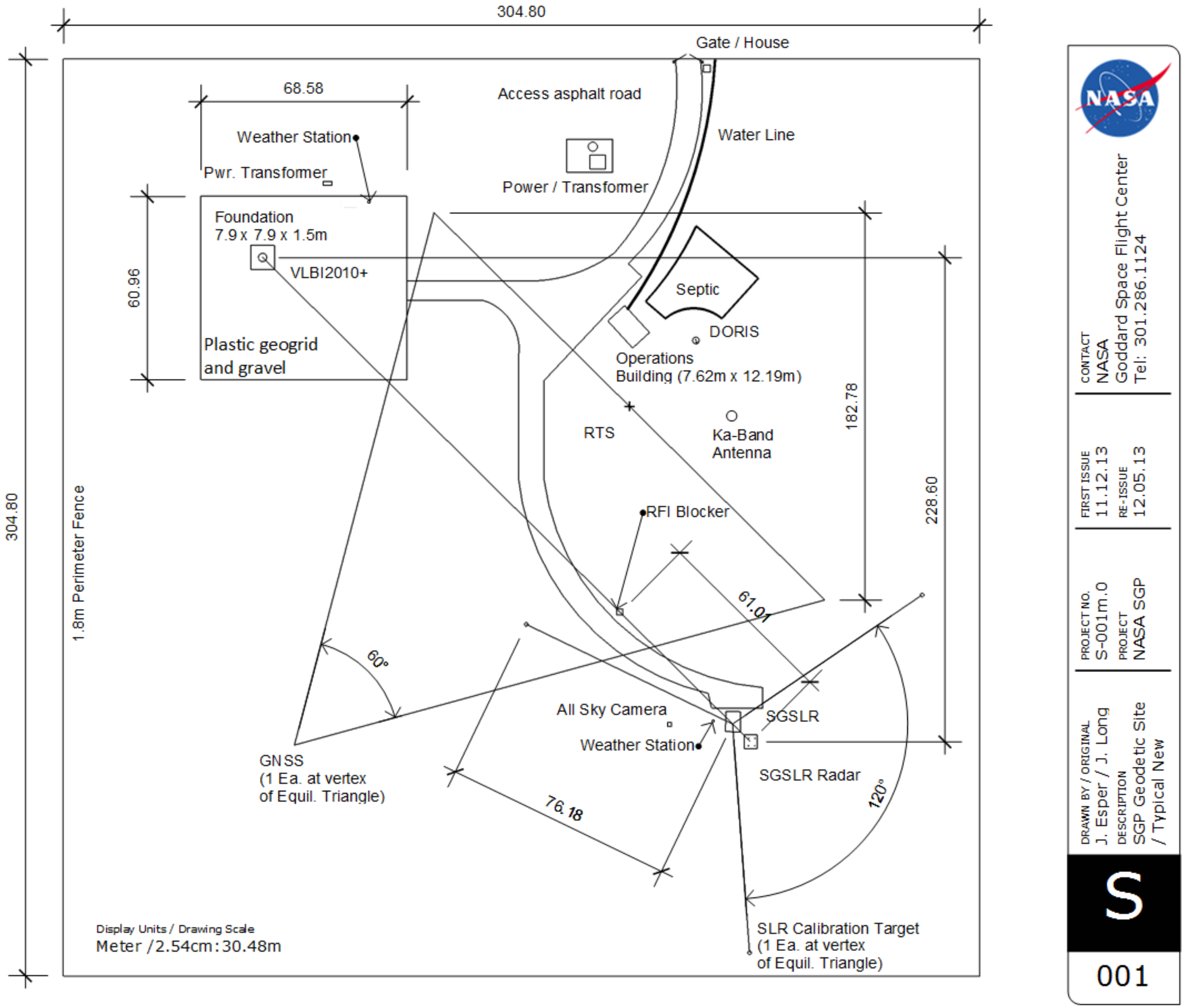
# NASA Space Geodesy Network Operations



# Co-Located Site Requirements

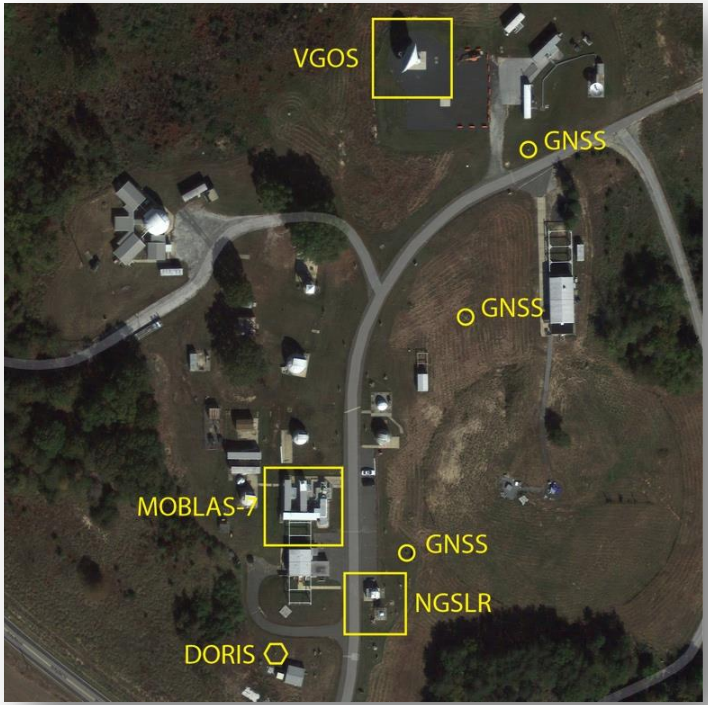
- Stable geology located away from known active faults and volcanic activity, ideally with bedrock outcrops
- The area surrounding the site shall be largely unaffected from loading transients
- Cloud Cover <= 50% average per year
- Atmospheric particulate content shall not interfere with the laser signal
- Located away from air traffic corridors and airports to protect aircraft from the SLR laser beam and minimize operational disruptions.
- Located away from RF emitters to minimize RFI
- Clear view down to 10 degrees elevation over 95% of horizon
- Available electrical power and broad-band internet

# Typical Site Layout



# Prototype Next-Generation Site

- The Goddard Geophysical and Astronomical Observatory (GGAO) in Greenbelt, MD is one of the few sites in the world to have all four geodetic techniques collocated at a single location.
- Demonstration of next generation prototypes completed in 2013.
- GGAO is the basis for upgrading and expanding NASA's global Space Geodesy Network.




*SLR*

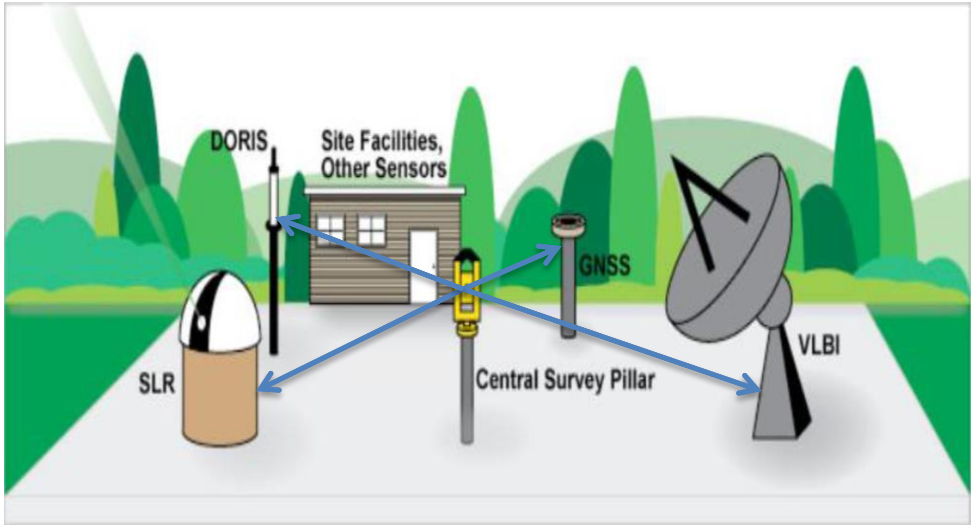
*VGOS*

*GNSS*

*DORIS*

# Vector Tie System at GGAO

- VTS at GGAO is based on the Leica TS30 Robotic Total Station (RTS), with the following accuracies (per manufacturer's specs.)
  - Horizontal and Vertical Angles: 0.5 seconds; Distances: 0.6 mm + 1ppm
- RTS Data Acquisition and Control Computer (RDACC): Allows operators to configure and remotely control the RTS and log measurements.
  - Find and identify target prism; verify prism correction
  - Process distances measurements to correct for atmospheric correction
- Local Tie results at precision of 1mm or less

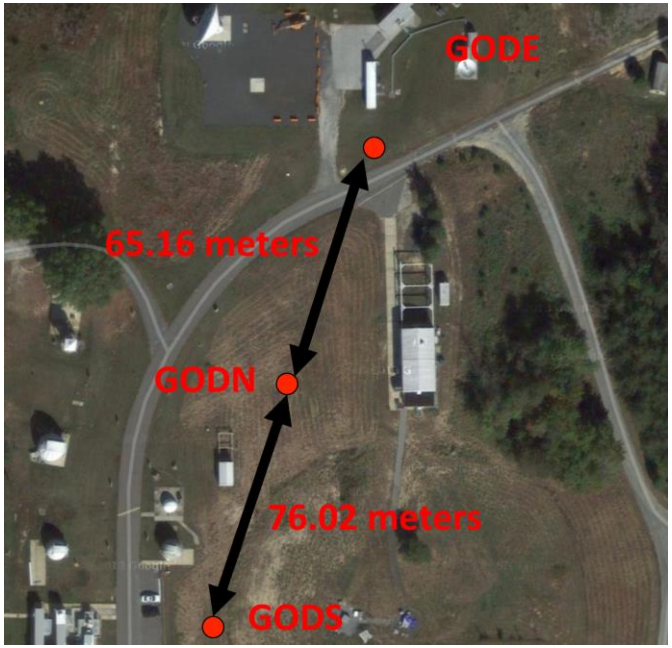



*Local Reference Frame tie to all geodetic Stations*

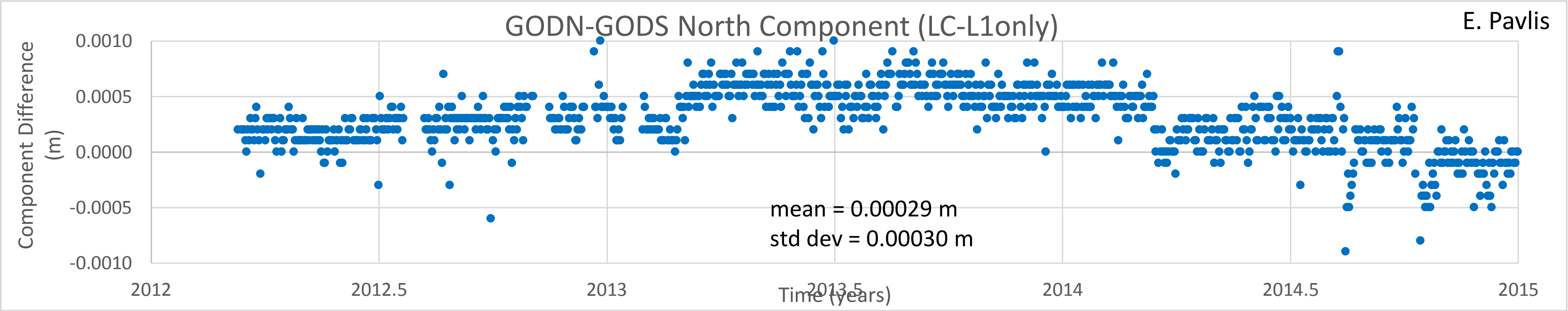
*GGAO Robotic Total (Range) Station*

# Multiple GNSS Stations Help Monitor Site Stability and Multipath Changes

- Standard deviation of GPS-based baseline lengths < 0.5 mm.
- < 1 mm agreement between baseline length from GPS and independent local tie survey.

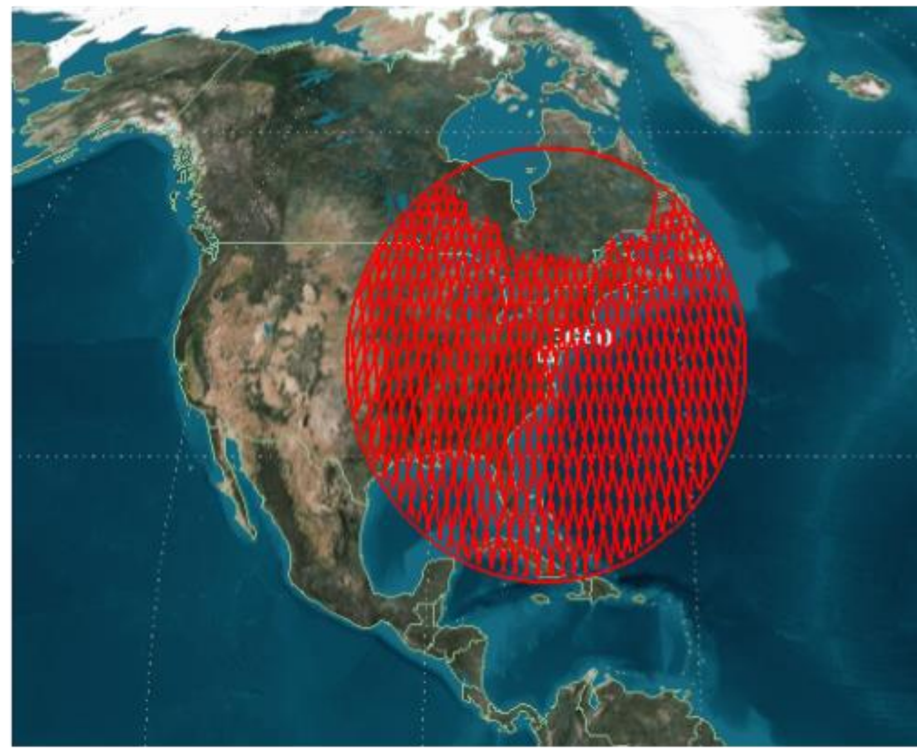



| 2012 Baseline Survey versus GPS for GODS to GODN | | | |
|---|---|---|---|
| | Survey (m) | GPS (m) | **Difference (mm)** |
| Length | 76.0252 | 76.0248 | **-0.4** |
| East | -19.8313 | -19.8314 | **-0.1** |
| North | -73.3829 | -73.3826 | **-0.5** |
| Vertical | 1.2247 | 1.2242 | **-0.4** |

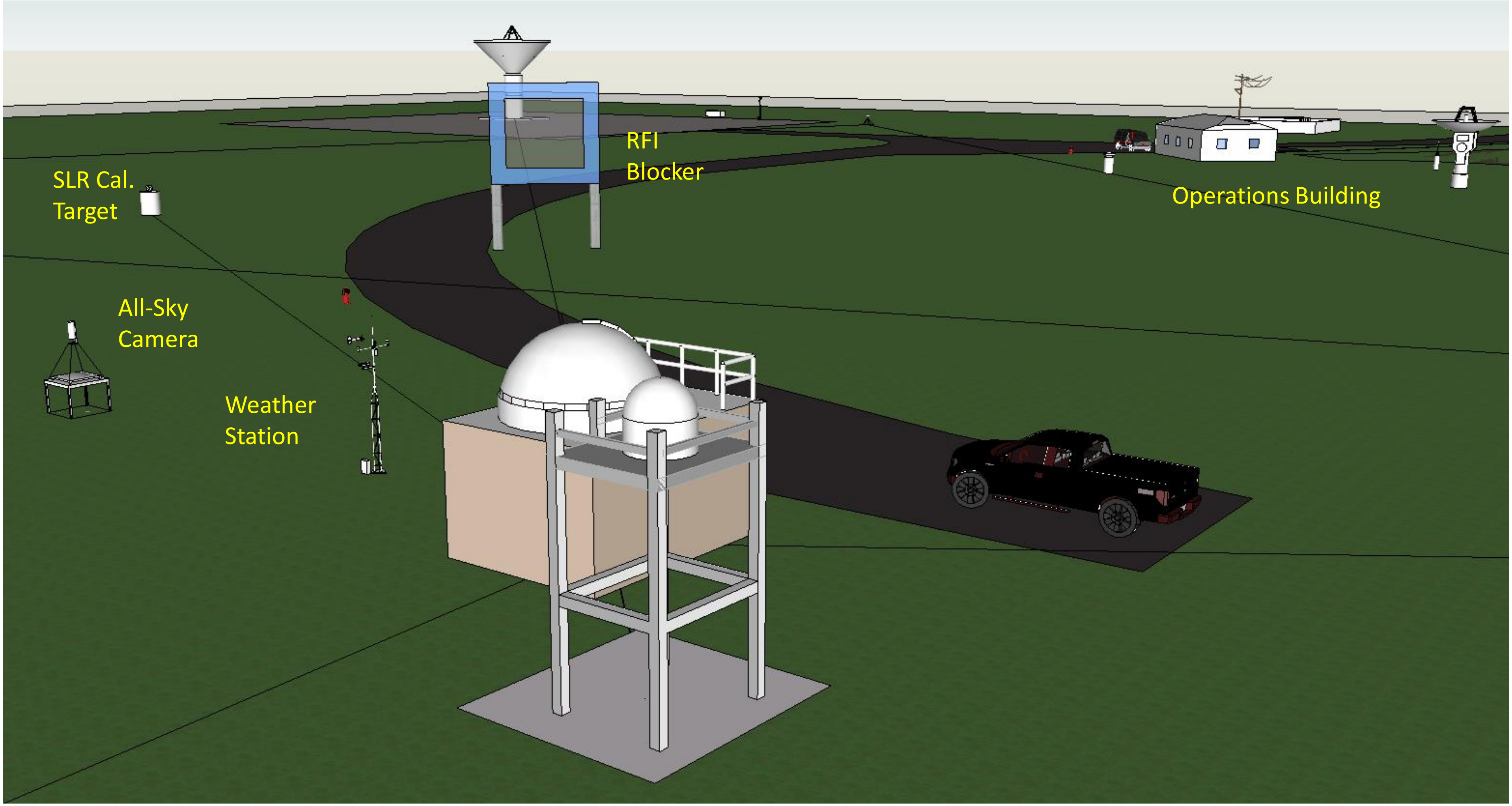


# Radar Masking

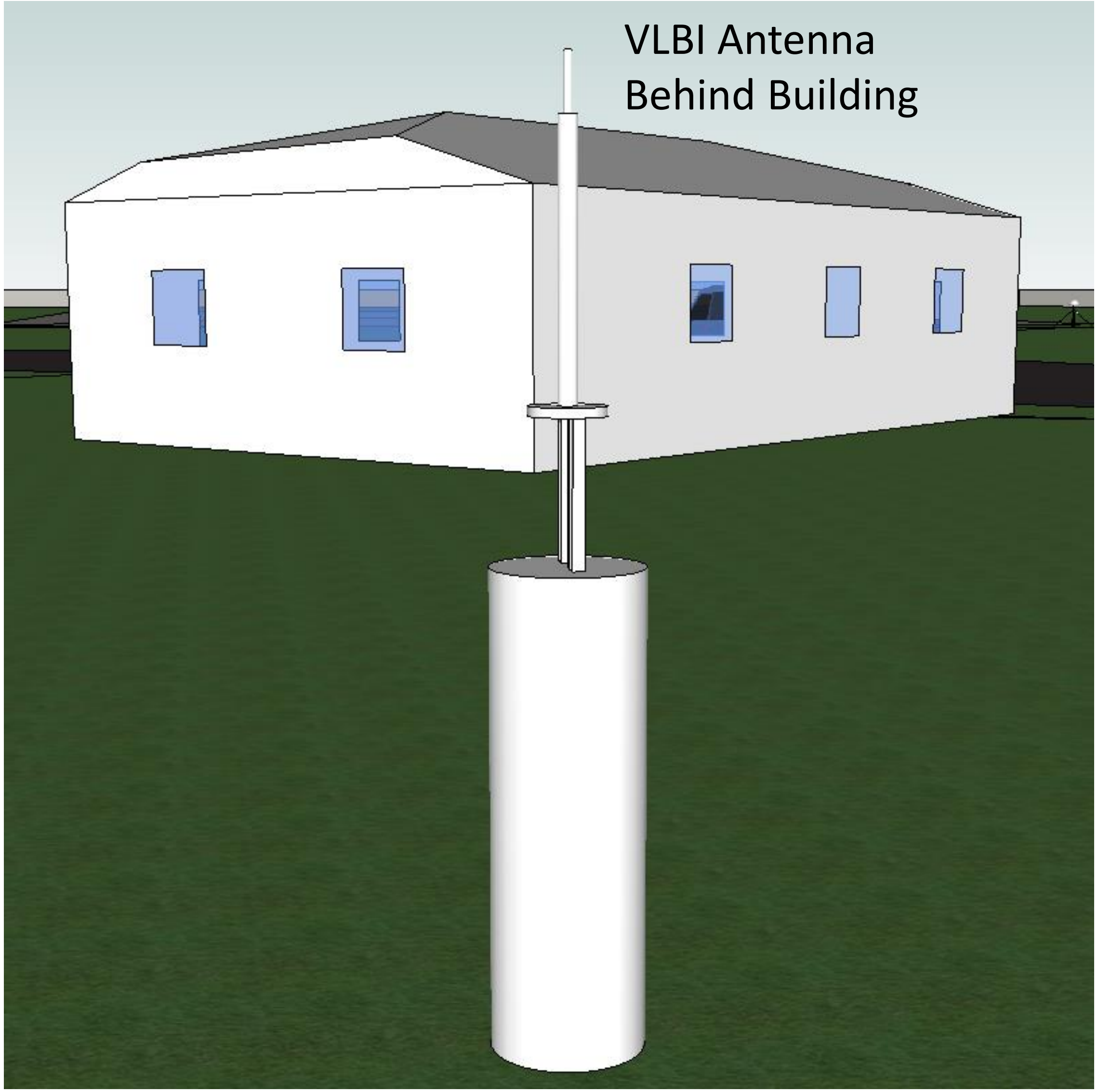
- Preventing VLBI and SLR from pointing at each other mitigates the risk of the radar damaging/interfering with VLBI.
- Masking reduces available SLR passes and a portion of the VLBI sky.
- Active coordination can minimize the mask and prevent direct pointing of the two system at each other.

# Flat terrain will require RF blocking



# Buildings can serve as good RF blockers



# A very small blocker can cast a large shadow

- A 3m x 4m stainless steel blocker 7m away from DORIS introduced 10-15 dB attenuation. This allowed linear operation of VLBI over the entire hemisphere.

# Texas - McDonald Observatory

- McDonald Observatory will host co-located VLBI, SLR, and GNSS stations.
- Deployment of the SGSLR will replace the existing MLRS.


# McDonald Site Assessment

| | MDO, TX | Notes |
|---|---|---|
| **SIT1: ITRF Site Stability / Continuity** | | |
| **SIT1.1**: SGP Site shall be located away from major plate boundaries and known active faults (> 100 km) and on bedrock. | 😐 | West Lobos Valley Quaternary fault zone about 80 km to the WSW with last major event 15,000 years ago.Last recorded earthquake with epicentral distances 40-70km in 2012 with mag. 3.6. |
| **SIT1.2**: SGP Sites shall only have secular (linear) motion, with stable rates, varying by ≤0.1 mm/y over a minimum of three (3) years | ☺ | From MD01 |
| **SIT1.3**: The area surrounding the site shall be largely unaffected from loading transients, i.e. historically no frequent major droughts or floods recorded, and local extraction or injection of underground liquids (water, oil, etc.) shall not result in significant (>10%) loading amplitude variations over time. | ☺ | |

| | | |
|---|---|---|
| **SIT2: NSGN Site Data Acquisition Requirements** | | |
| **SIT2.1.1**: Cloud Cover shall be <= 50% average per year. | ☺ | |
| **SIT2.1.2**: Atmospheric particulate content shall not interfere with the laser signal. | ☺ | |
| **SIT2.1.4**: NSGN Sites shall be located away from air traffic corridors and airports to protect aircraft from the SLR laser beam and minimize operational disruptions. | ☺ | MLRS is about 18 km from a Military Operations Airspace. No issues with current SLR operations have been reported. |
| **SIT2.2.1**: NSGN Sites shall be located away from external RF emitters. | ☺ | VLBI location in valley puts it away from Mt. Fowlkes communications antenna. RFI at location must be measured. |
| **SIT2.2.2**: NSGN Site average sustained wind speed per year shall be < 40 km/hr (25 mph) | ☺ | |
| **SIT2.2.3**: NSGN Site Primary operating conditions shall be in the temperature range –15C to 33C. | ☺ | |
| **SIT2.3**: NSGN Sites shall have a clear view down to 5 degrees elevation over 95% of horizon. | 😐 | VLBI meets requirement over 83% of horizon. |

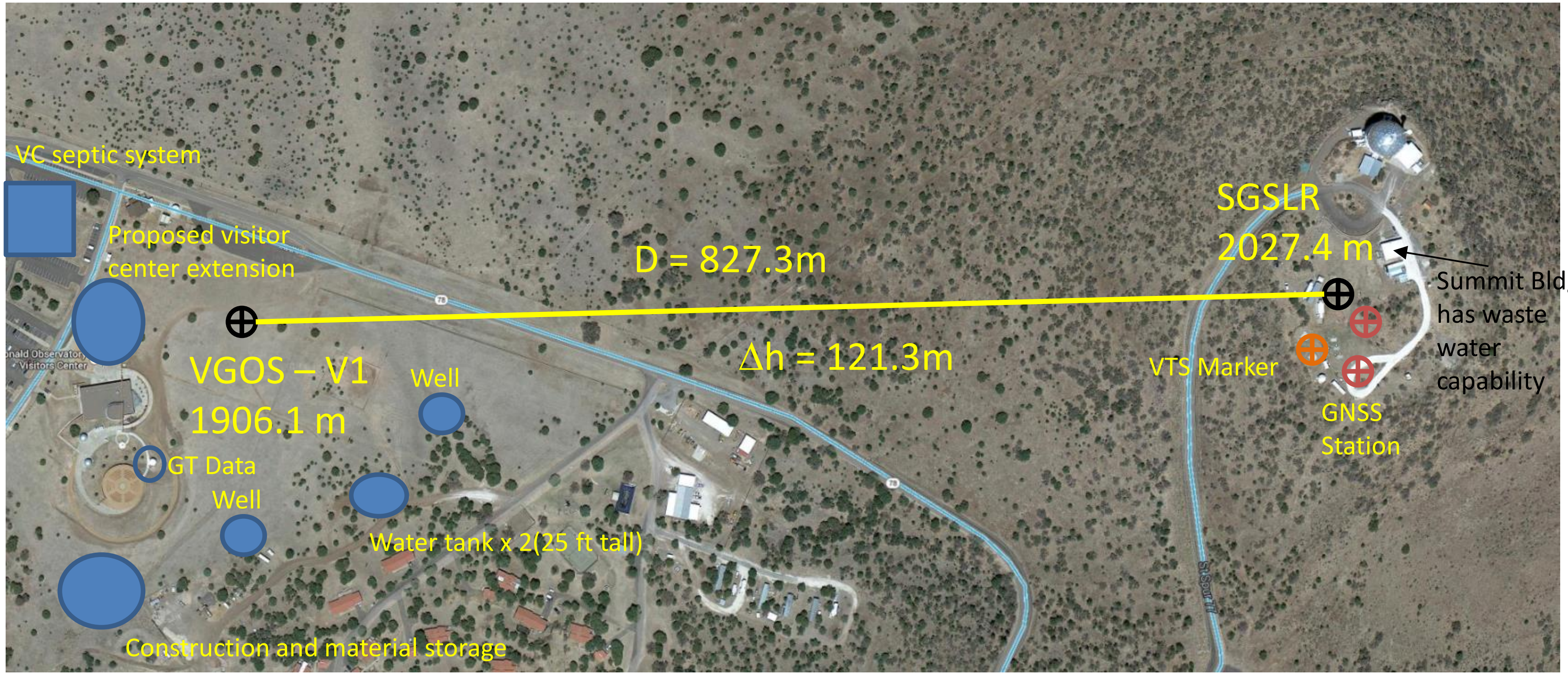
| **SIT3: Site Infrastructure Requirements** | | |
|---|---|---|
| **SIT3.1.1**: NSGN Sites shall have at a minimum commercial Internet service | ☺ | |
| **SIT3.1.2**: NSGN Sites shall be capable of hosting a dedicated communications terminal for satellite data transmission through commercial and/or NASA assets. | ☺ | Satellite communications possible if needed. |
| **SIT3.2**: Electrical power shall be available to NSGN Sites. | ☺ | |
| **SIT3.3**: A typical NSGN Site shall have an area (1000 x 1000) sqf (305 x 305) sqm | ☺ | |

Quality Score = 13.0/14

Green = 1 pt.
Grey = 0.5 pt.
Red = 0 pt.

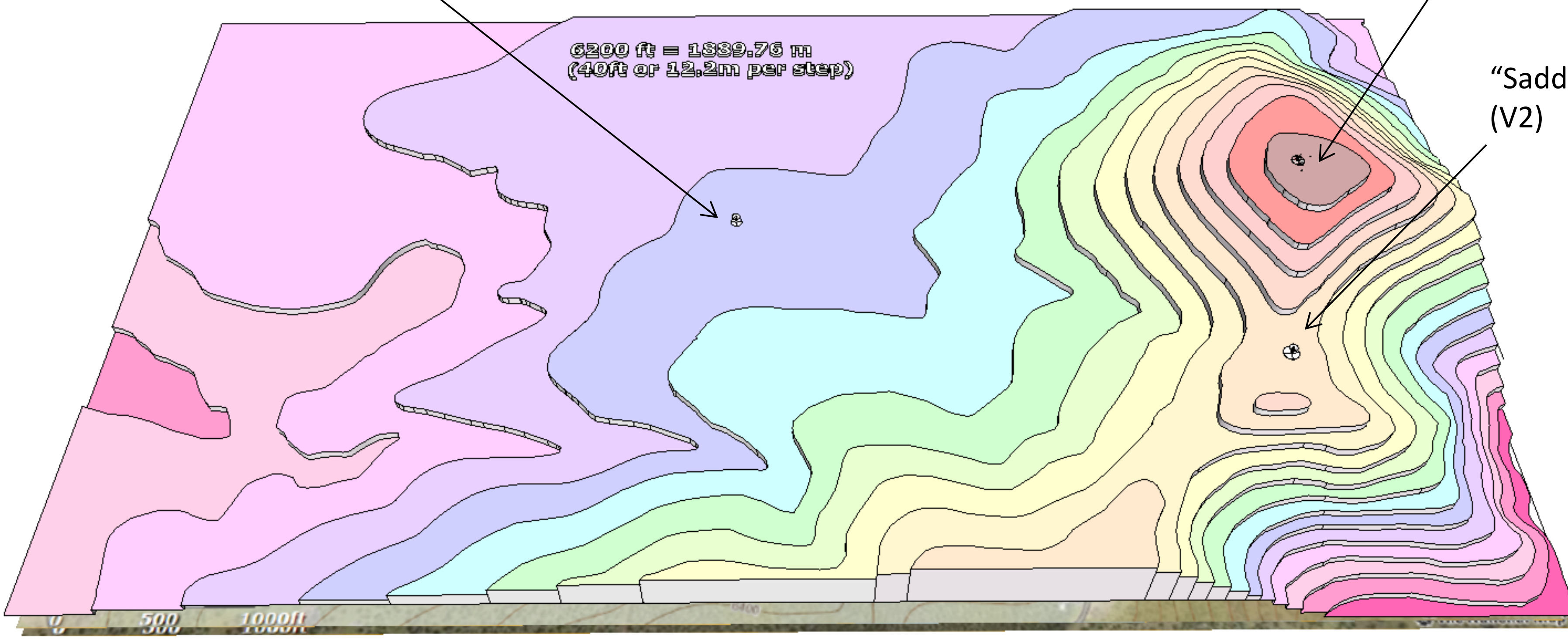
# Proposed V1 - Core Site Layout

- Location of SGSLR and VGOS.
- Each location to have 2 GNSS stations.
- VTS system retro-reflectors at each site.
- SGSLR calibration targets.
- Robotic Total Station (RTS) visibility of GNSS Stations (2 total).



# Taking Advantage of Natural Terrain

- 40m vertical resolution of the areas of interest.



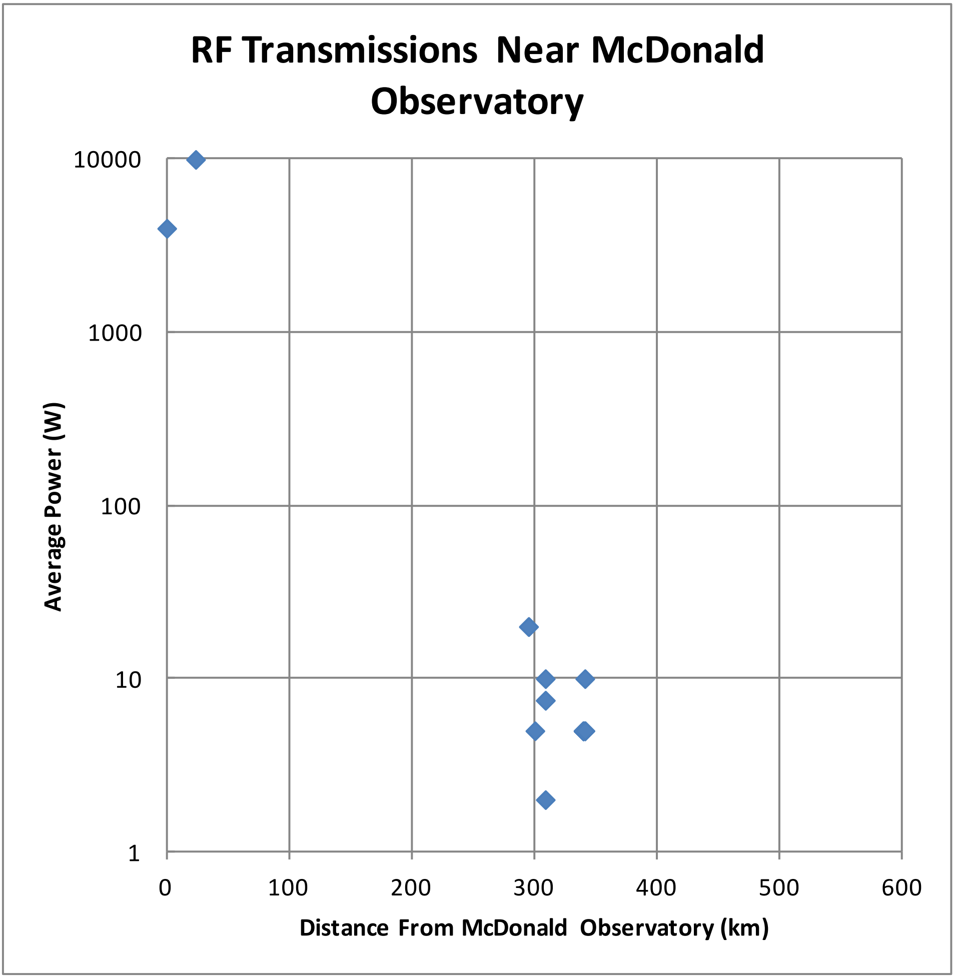
# VGOS V1 Location

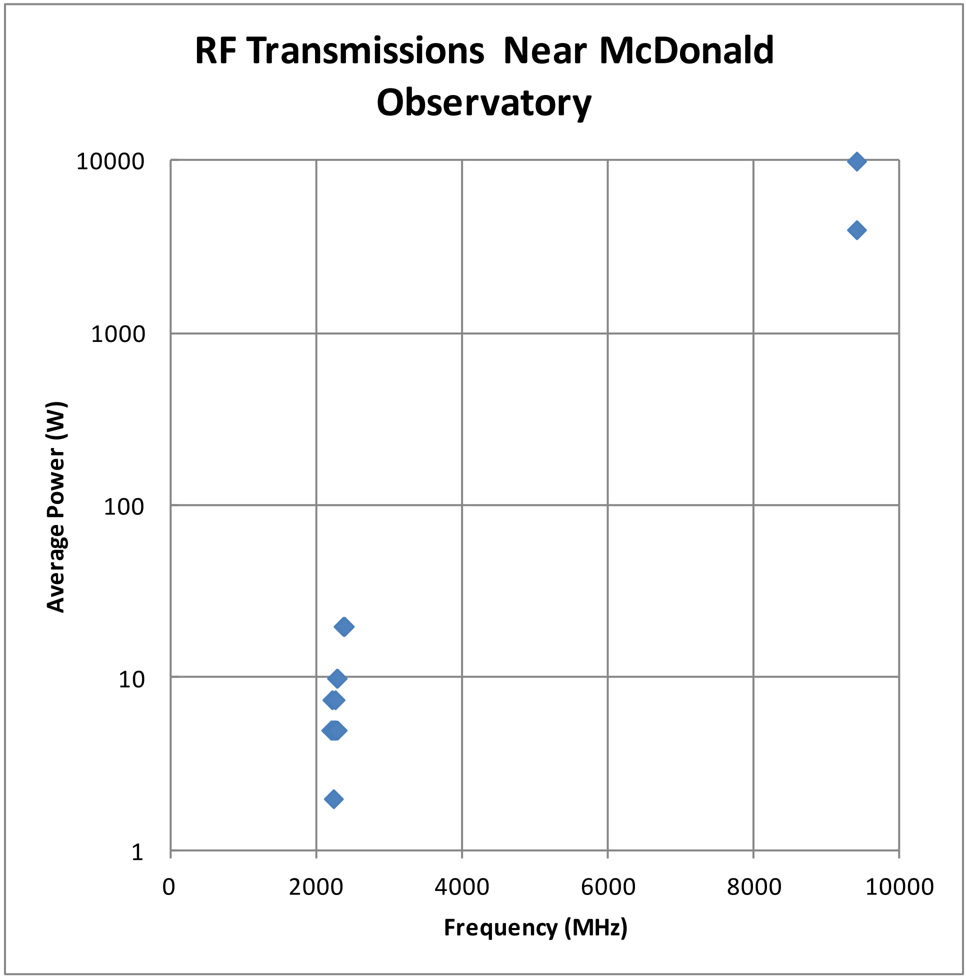
- V1 location determined to be the most likely candidate for the VGOS Station.

View of V1 location from RTS1 @ SGSLR from 10 ft. height.

View of RTS post from V1

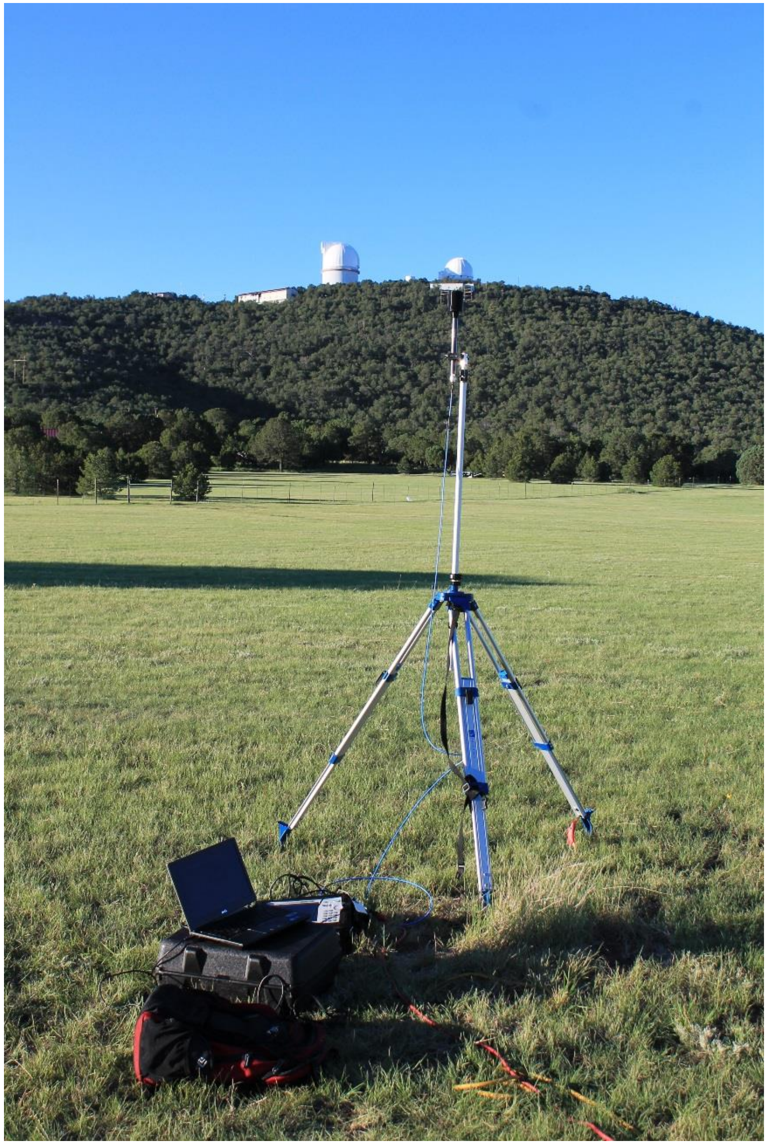
# Known RF Transmissions Near McDonald Observatory

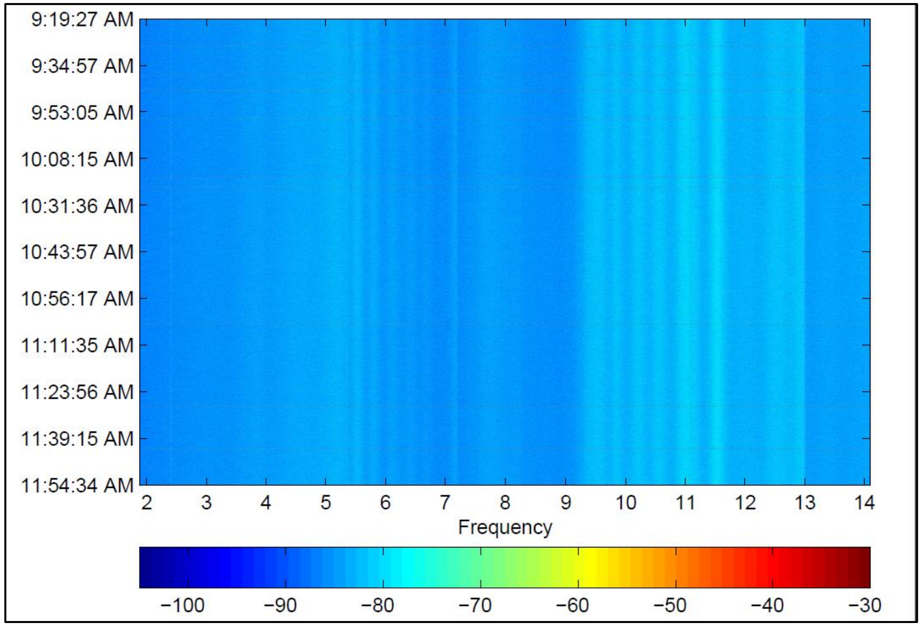



Aside from the known on-site RF transmitting antennas, there are no known RF transmitters of relevance in the immediate vicinity. Nearest are ~300 km away.

# Trust, but verify…






No detected RFI that would cause saturation of the VGOS antenna at the planned MCD location

# Summary

- Big year for VGOS – broadband is coming!
- Site selection and layout must take into account the unique requirements of all techniques as well as those to improve the ITRF.
- RFI, particularly from SLR radar, is a key consideration in site layout.
- Texas site on-track for implementation by end of the decade.