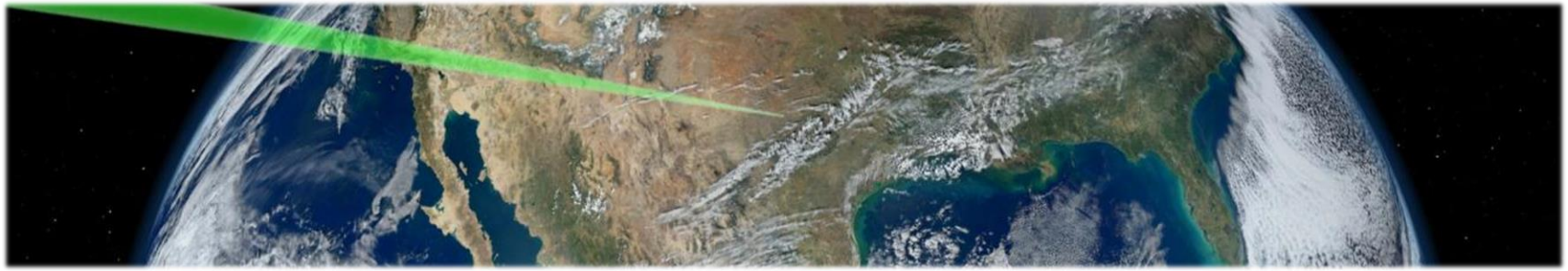

Development Progress on NASA's Space Geodesy Satellite Laser Ranging System

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1 – NASA Goddard Space Flight Center
2 – KBRwyle
3 – Sigma Space
4 – Cybioms

Space Geodesy Satellite Laser Ranging

- Measurement of changes in the mean sea level will require a Terrestrial reference Frame with an accuracy of 1 mm (decadal scale) and a stability of 0.1 mm per year (annual scale).
- To meet this need, NASA is implementing a Next Generation Space Geodesy Network, that will replace the legacy SLR and VLBI network with up to 10 globally distributed sites with co-located SLR, VLBI, and GNSS (and many with DORIS).
- SGSLR shall be capable of both local and remote operation by an operator, with a clearly defined path for transitioning to a fully automated mode

Data Volume Estimates

Data volume from ILRS Global Report Card: April 2013 thru March 2014

Site ID	Station Number	LEO NP Totals	LAGEOS NP Totals	High NP Totals	LAGEOS Average Precision (mm)	JCET Long Term Stability (mm)
YARL[1]	7090	176,683	20,634	21,986	1.9	2.5
GODL[2]	7105	76,554	7,666	3,052	2.0	3.5
CHAL	7237	69,438	7,235	14,735	0.8	4.1
STL3	7825	78,089	7,218	3,984	1.9	1.5
GRZL	7839	75,714	5,468	18,016	0.2	1.8
HERL	7840	38,592	7,018	6,069	1.9	1.2
WETL	8834	46,509	5,053	12,683	1.6	3.0
SGSLR(20°)	@7105	53,400	7,400	12,200	<1.5	<1.8
SGSLR(10°)	@7090	200,000	18,500	26,400	<1.5	<1.8
Requirement		45,000	7,000	10,000	<1.5	<2.0

Projected SGSLR annual NP data volume[3]:

(20°) 50% weather outage, 16% other outage, 40% data collection when active, min 20° elevation

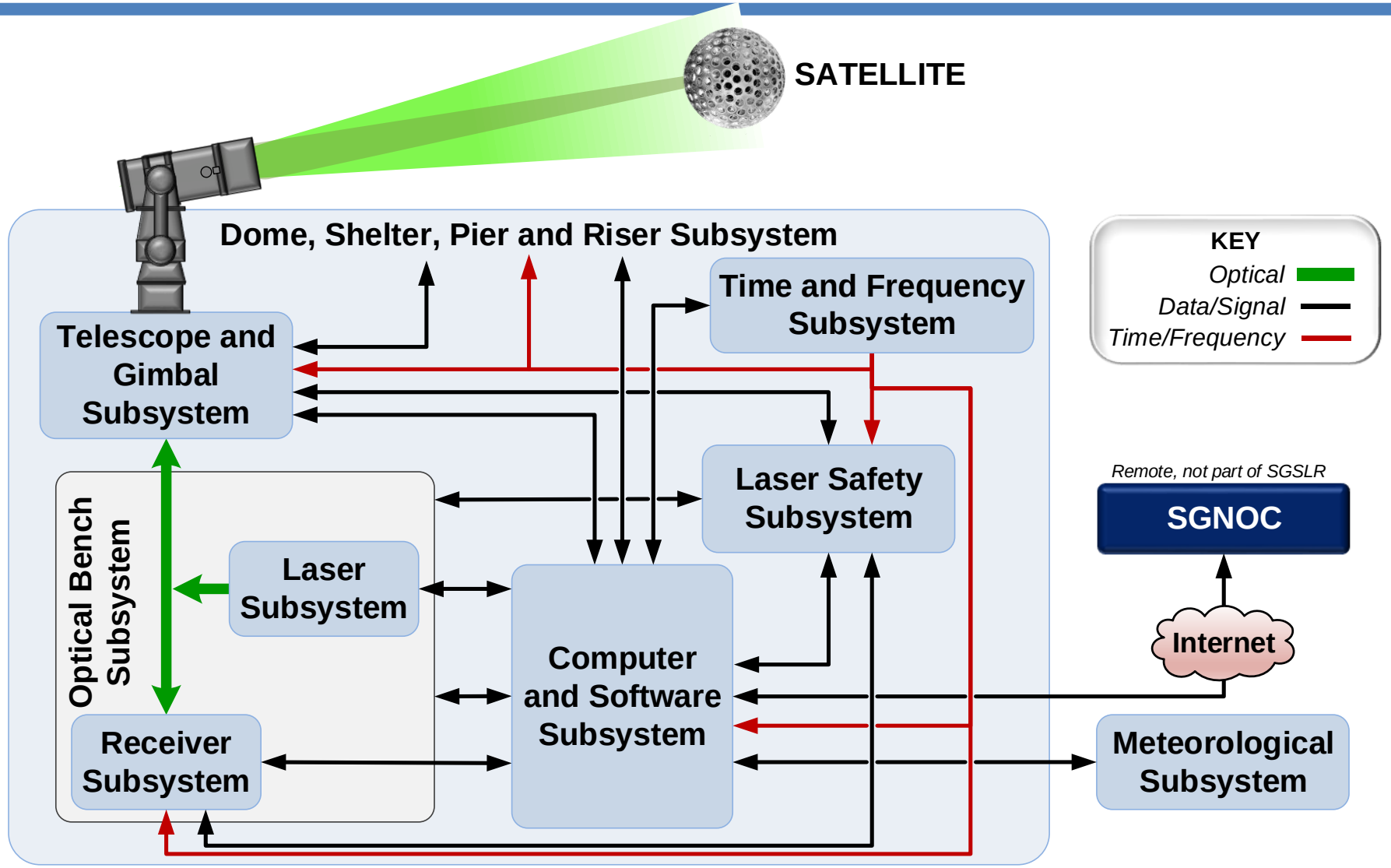
(10°) 14% weather outage, 16% other, 40% data collection when active, min 10° elevation

[1]YARL has 14% weather outage and tracks to 14° elevation

[2]GODL has 50% weather outage and tracks down to 10° elevation

[3]Precision and stability numbers for SGSLR are based upon SGSLR analysis and NGSLR performance

Internal Interface Overview



Drawing D-011a

Status since Riga Workshop (October 2017)

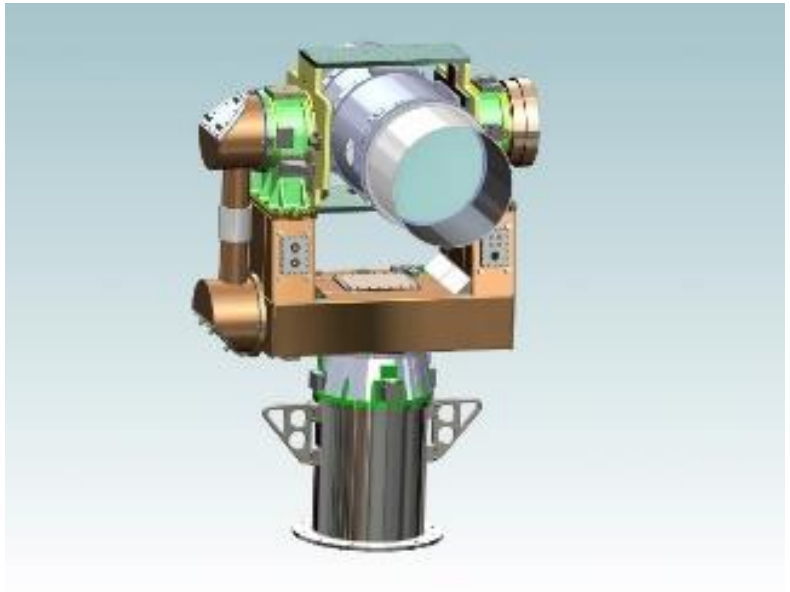
- MCP PMT array for receiver instead of SiAPD.
- Optical Bench design matured and been peer reviewed.
- IT Security and Network Architecture design now fully meets NASA requirements.
- The color Alcor All Sky Camera has been chosen for local and remote operations.
- Testing with gimbal at Cobham allowed interfaces with software to be fully understood and provided some preliminary performance testing with the gimbal.
- Construction of SGSLR facilities is currently taking place at both McDonald Geophysical Observatory (MGO) and at the Goddard Geophysical and Astronomical Observatory (GGAO).
- Baader dome procurement is in progress for both MGO and GGAO.
- Critical Design Review for SGSLR was given on 5 and 6 September 2018 to a NASA/Goddard independent review panel. The SGSLR team passed the review and are now moving on to the build process

Telescope and Gimbal Subsystem

- Key Specifications
  - Absolute Pointing ≤ 3 arcsec RMS
  - Jitter ≤ 1 arcsec
  - Invariant Point Knowledge space ≤ 1 mm in 3D
- Telescopes currently being fabricated
- Gimbal unit 1 and controller are undergoing testing at the manufacturer
  - The manufacturer has constructed their own SLR shelter for extensive factory testing
- SGSLR team initiated testing at the vendor facility
- For more information on GTA testing, please see **Status of the NASA SGSLR Gimbal and Telescope Assembly Build and Test** in poster session

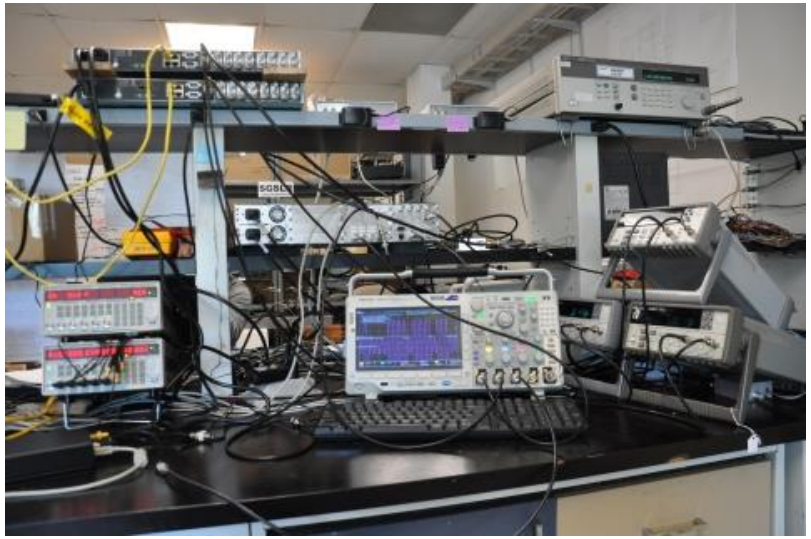
Telescope and Gimbal Subsystem

- Vendor to complete Telescope and Gimbal assembly for each site
- Conduct Factory Acceptance Tests (FAT) – Spring 2019
- Install GTA 1 at GSFC / GGAO site and perform Site Acceptance Tests (SAT) - Summer 2019
  - Deploy GTA #1 to Ny-Ålesund after SAT
- Install GTA 2 at GSFC / GGAO site and perform Site Acceptance Tests (SAT) - 2019
- Install GTA 3 at MGO site and perform Site Acceptance Tests (SAT) - 2019

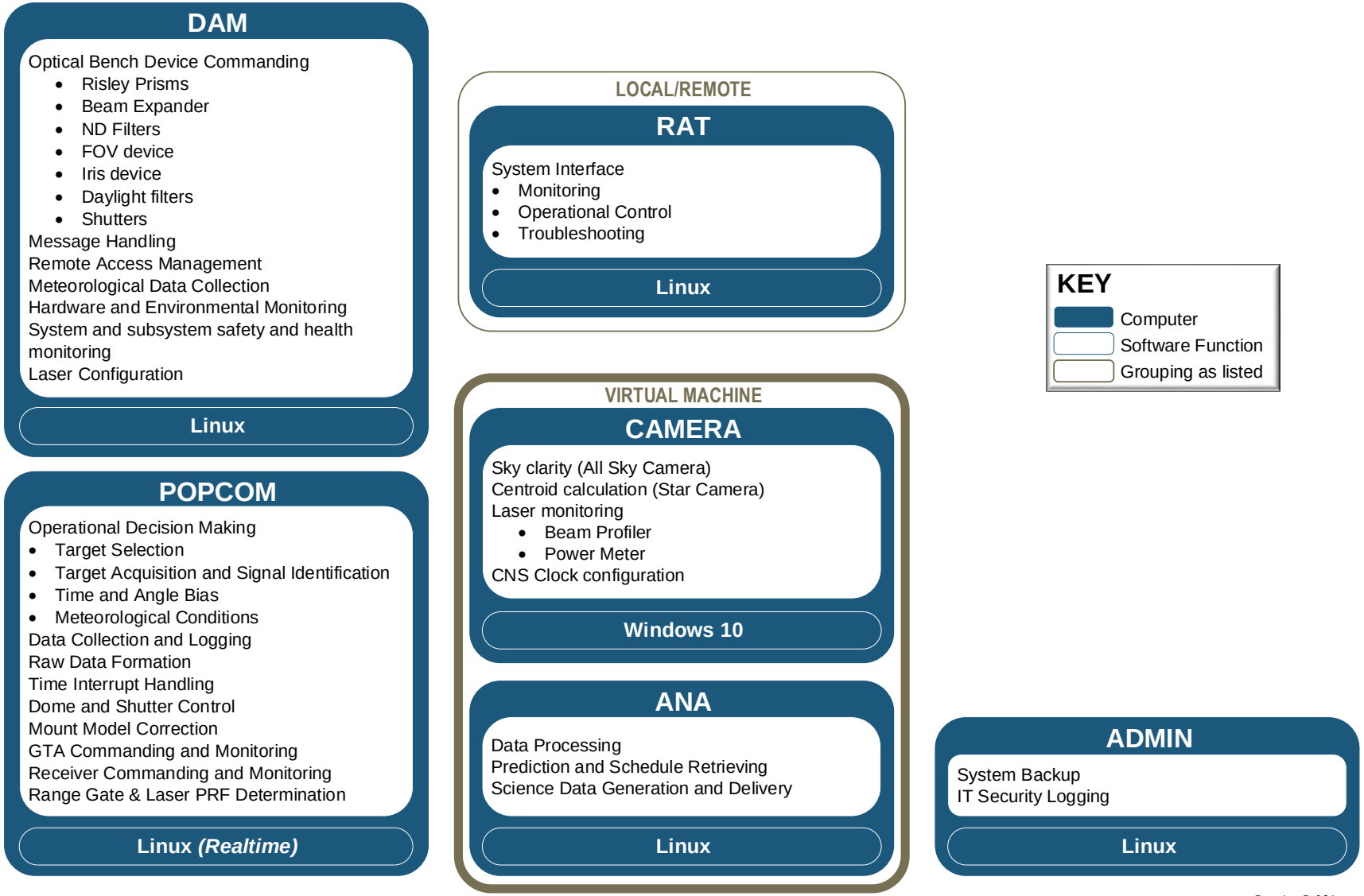


Time and Frequency Subsystem

- 10 MHz, IRIG-B, PPS Distribution
  - Frequency Source: Microsemi S650
  - Initial testing showed offset in 1 PPS, corrected by manufacturer via firmware
- Major components have been procured
- Component testing in progress with many complete
- Custom chassis have been assembled and are undergoing characterization and testing



Software Design / Main Functions



Drawing D-981a

Software Progress

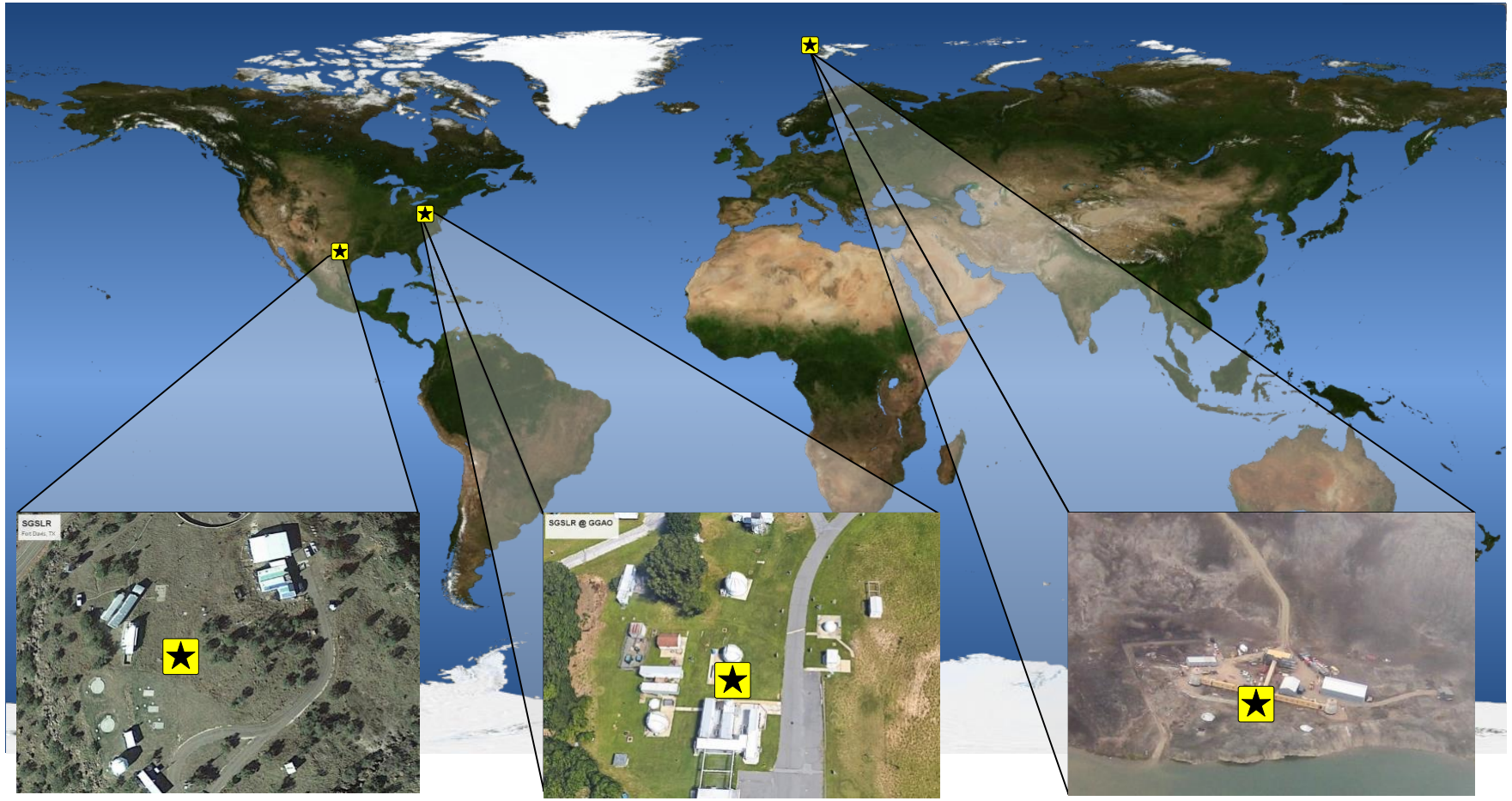
- Current software is preliminary operational version for GTA testing. Current status:
  - GTA interface working
  - Timing interface working
  - MET software installed and partially tested
  - Star calibration installed and partially tested
  - Sunlit satellite software installed and partially tested

- Current efforts:
  - Full GTA FAT/SAT version , include tested and working software with all of the above
  - Preliminary version of the dome interface.

- Next version of software will have added:
  - Ranging Control Electronics
  - Laser Safety Interface
  - Receiver Simulator.

- Operational Software build 1.0: (needed for collocation, expected in 2020)
  - All of the above
  - Optical Bench
  - Full Receiver

Planned SGSLR Locations



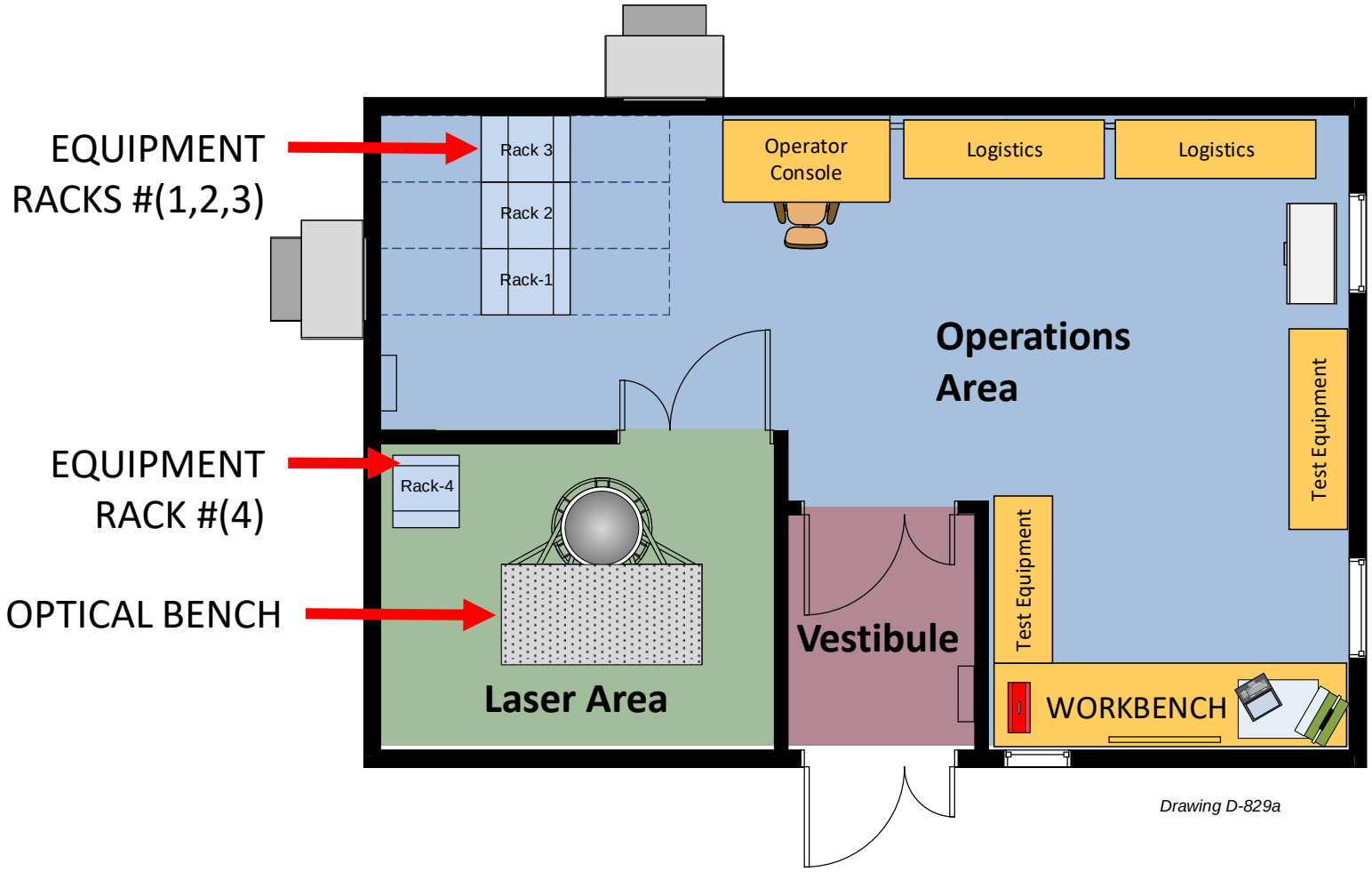
Drawing D-014b

McDonald Observatory, TX (MGO)

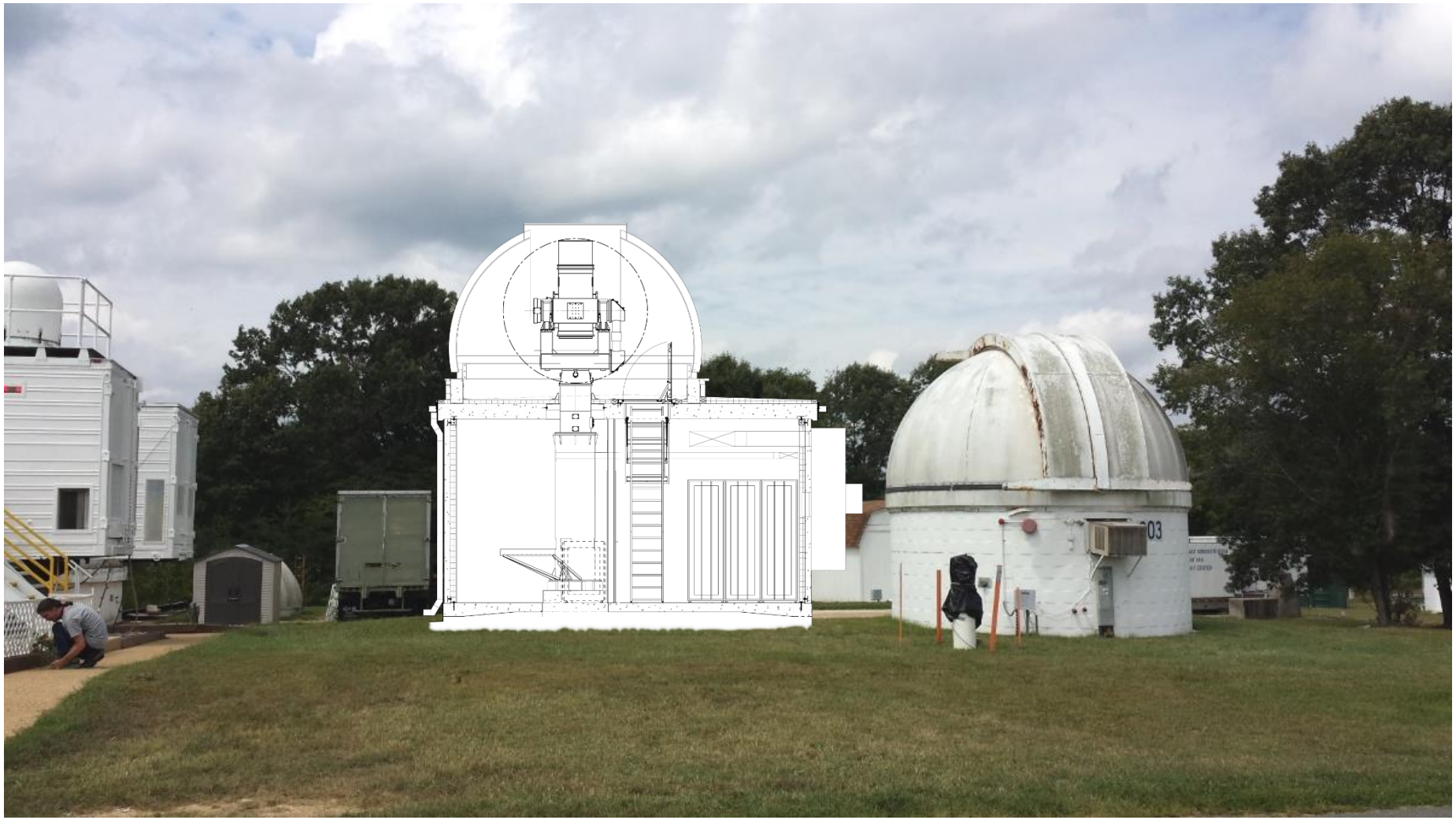
Greenbelt, MD (GGAO)

Ny-Ålesund, Norway (NGO)

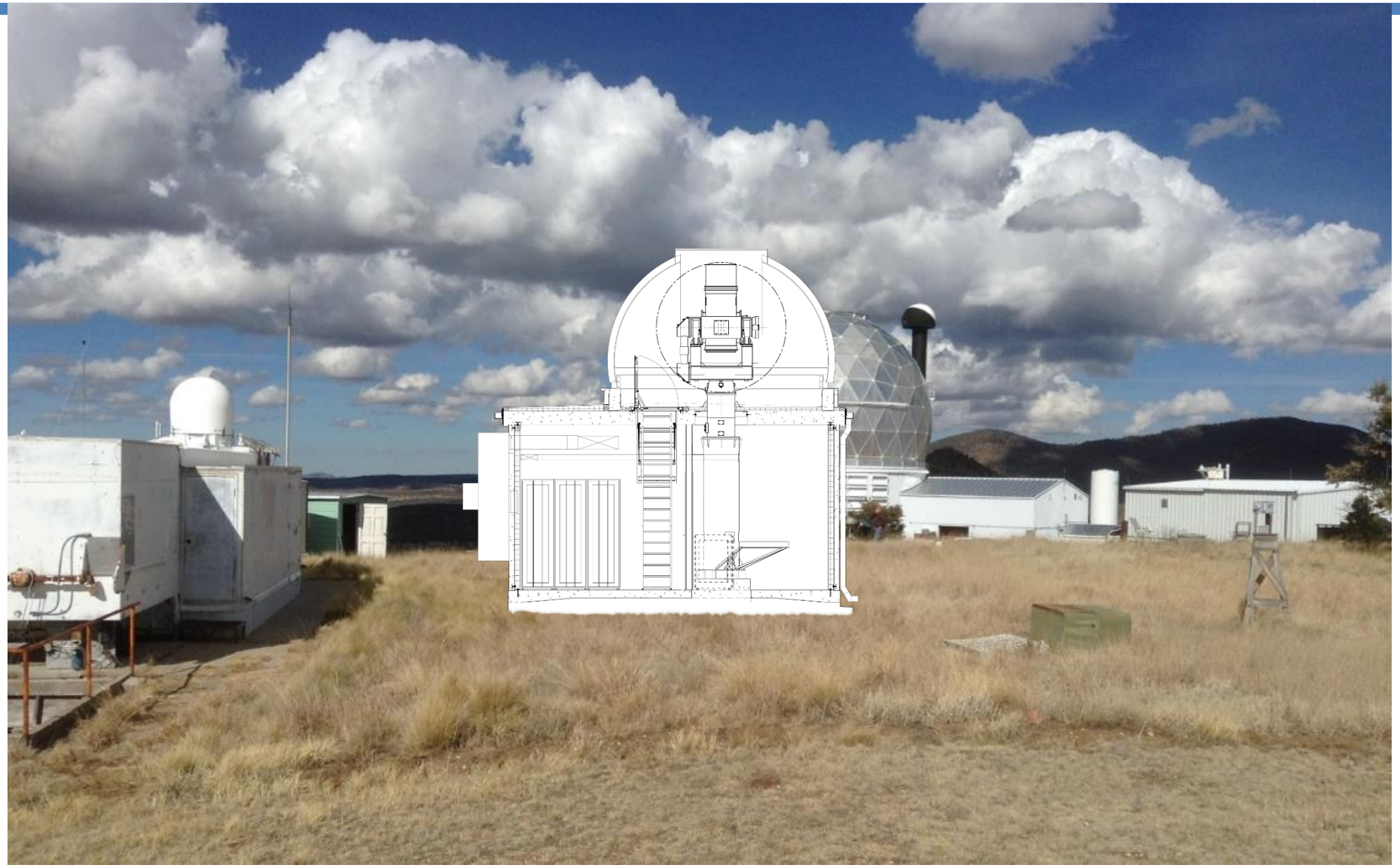
Shelter – Plan View



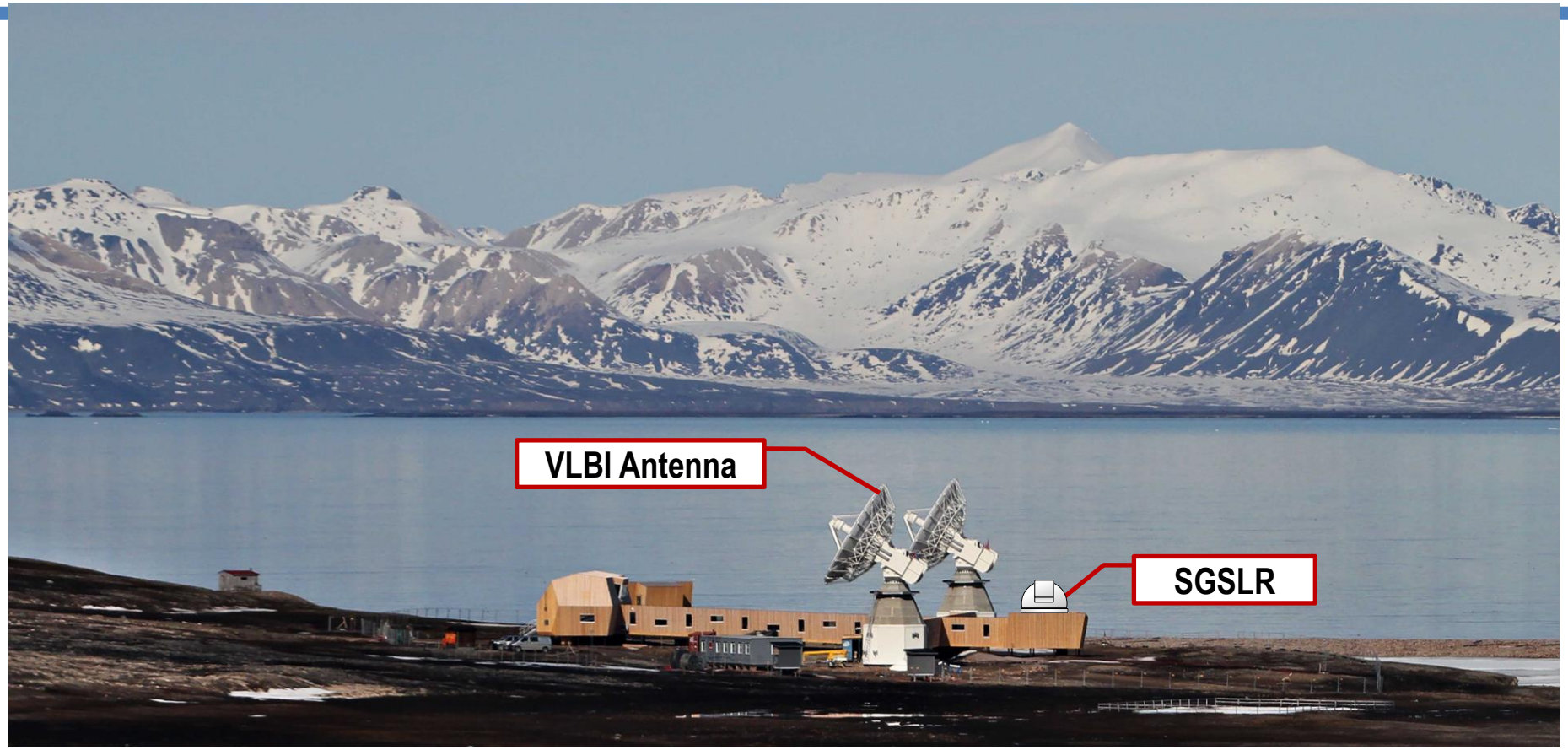
Site Layout: GGAO



Site Layout: McDonald Observatory



Site Layout: Ny-Ålesund



NOTES:

- Shelter already constructed; Dome not yet installed
- Unique shelter design
- Co-located with VLBI

Site Construction

- GGAO
  - Ground breaking the week of Nov 1st, 2018
  - Scheduled shelter completion: Late Spring 2019
- MGO – Texas
  - Pre-construction meeting in early December 2018
  - Pad, pier and roads complete by end of December 2018
  - Scheduled shelter completion: Early Summer 2019
- Ny-Ålesund
  - Shelter is already constructed (different design)

Pier at MGO

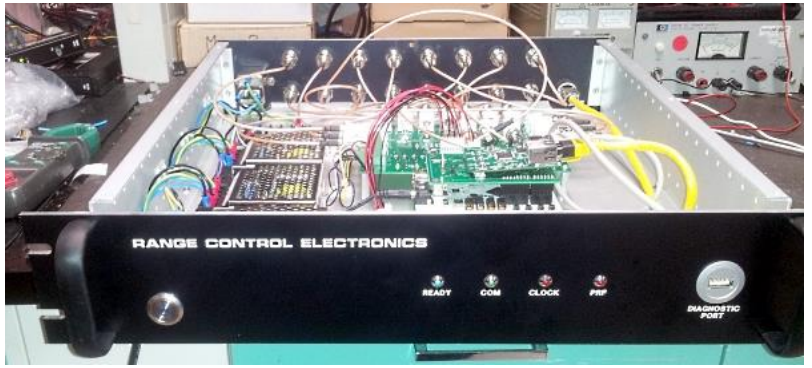
Receiver Subsystem

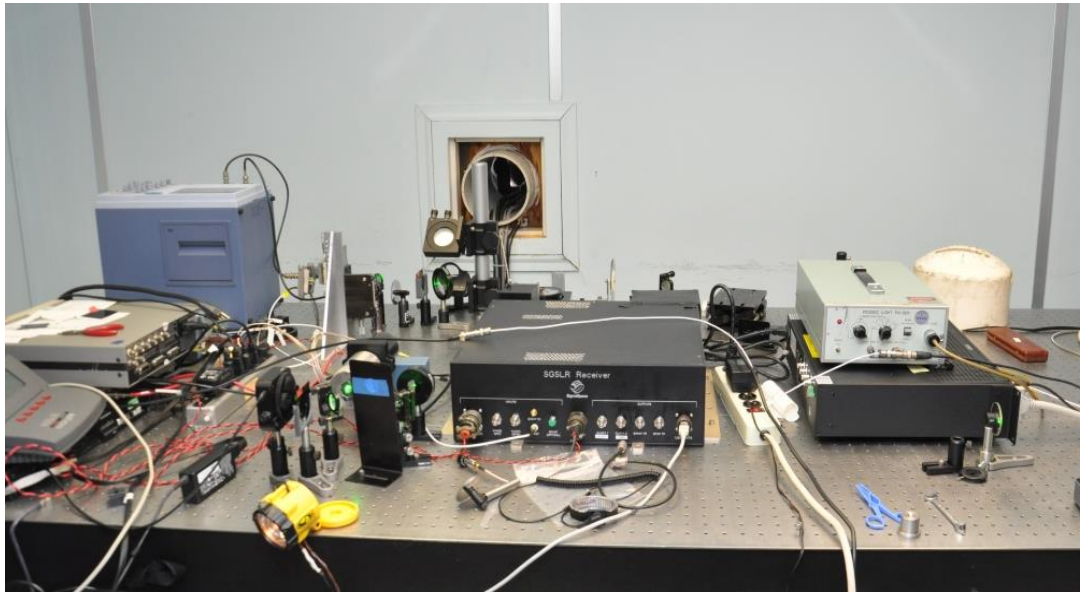
- Receiver
  - Detects and time tags start (transmit) and stop (receive) ranging events
  - Precisely relates ranging events and ancillary signals to UTC
  - Provides angular offset information to allow pointing corrections
- Range Control Electronics (RCE)
  - **Generate** a gate that 'windows' a Satellite OR Calibration (Ground/Internal) corner cube return for sensor detection in the Receiver Subsystem
  - **Generate** a 'Laser Fire' Command signal BUT not at the same time a window signal appears

- For more information on choice of pulse repetition frequency and and window generation, see **NASA SGSLR Approach to Range Gate and Fire Command Control** in the poster sessions.

Receiver Subsystem

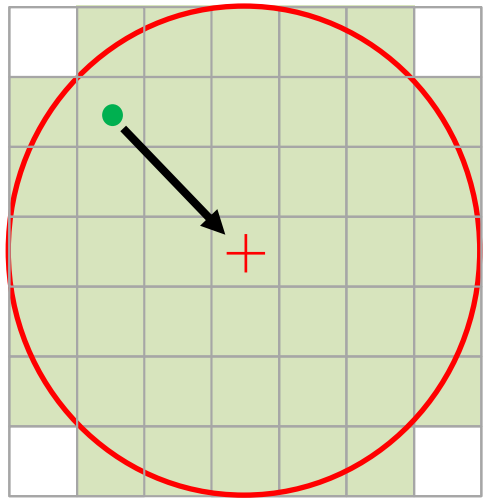
- Prototype RCE
  - Assembled and undergoing testing
  - Designed and produced by KBRWyle
- Prototype Receiver
  - Assembled and is undergoing testing
  - Design incorporates lessons learned during testing at GGAO
  - Designed and produced by Sigma Space





SGSLR Receiver Overview

- Provide Closed Loop Tracking
  - 7x7 pixelated detector array
  - 4 pixels in corners unused
  - Count # of events in each pixel to determine satellite location
  - Signal location used by C&S subsystem to correct angular position to maximize return signal strength

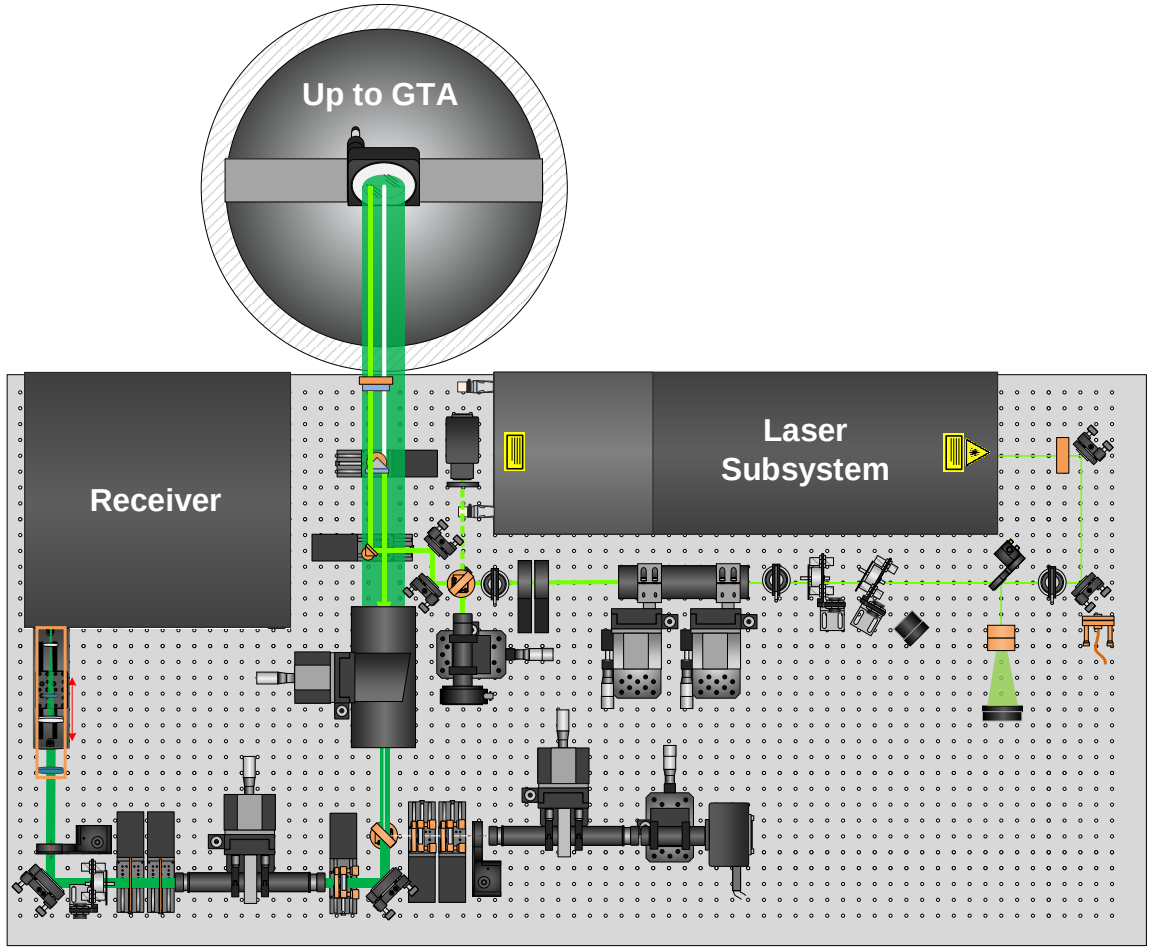


- Make Precise, High Resolution Timing Measurements
  - Start Events: Single measurement per shot
  - Stop Events: Multi-stop, low dead-time
  - Ancillary Events (e.g., 1 PPS)

- Selection based on proven heritage hardware from aircraft and space-flight designs
  - SGSLR event timer hardware with improved higher resolution has been demonstrated in the lab

Optical Bench Development

- Engineering peer review for the optical bench was completed and passed in February 2018
- Optical Bench components are being procured and construction/testing is underway



Baader Dome

- First dome scheduled for FAT the first week of December with installation scheduled to be in March 2019.
- Second dome will be finished around March 2019 with installation in Texas in June 2019.
- Third dome installation in Ny-Alesund scheduled for the Fall 2019

Summary

- SGSLR has successfully completed its critical design review and is in its build phase.
- The gimbal and telescopes are currently in production, with the first gimbal currently undergoing testing. Factory acceptance tests in Spring 2019
- Time and Frequency subsystem being assembled and tested
- Software for GTA control and testing mostly complete, currently testing and working on dome integration
- Receiver subsystem prototype being constructed and tested
- Ground breaking for GGAO SGSLR shelter as of this presentation! Others to follow
- Optical Bench undergoing construction and testing
- First Baader dome to be installed in January 2019
- Collocation expected to begin in 2020