

# Upgrade of the NGSRLR Optical Bench and Resulting Performance Improvements

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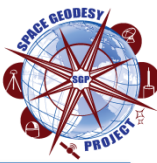
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Fujiyoshida, Japan

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# Abstract

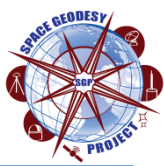


After several years of field development and satellite laser ranging operations, the Optical Bench has undergone many incremental changes to accommodate increased demands on the capabilities of the NGSRL. Initially designed for low energy, eyesafe laser ranging, the Optical Bench has been modified to handle energies needed to perform daytime GNSS tracking as well as meet newly developed American National Standards Institute (ANSI) and Federal Aviation Administration (FAA) safety requirements.

In time, it was realized that an overall design change was essential to better accommodate iterative upgrades, allow for full use of increased laser power, provide more precise and efficient optical alignments, and incorporate lessons learned thus far from SLR operations. We will review the initial design of the Optical Bench and its implementation as well as discuss the upgrades, the supporting reasons, and the improvements in system performance because of this upgrade.

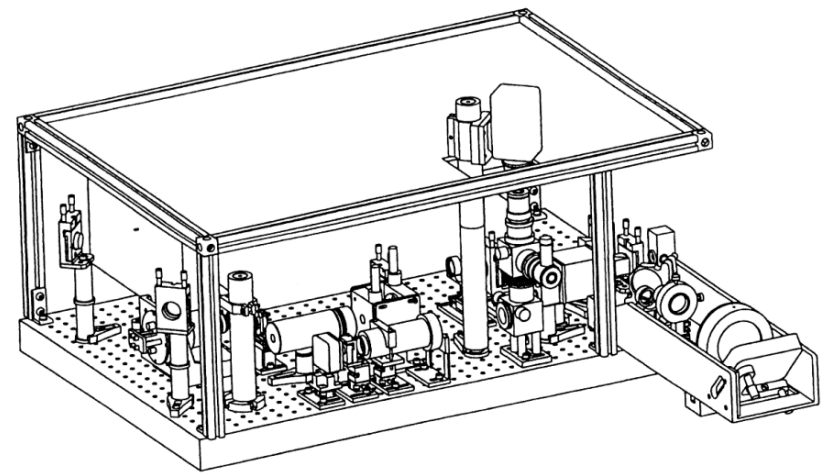
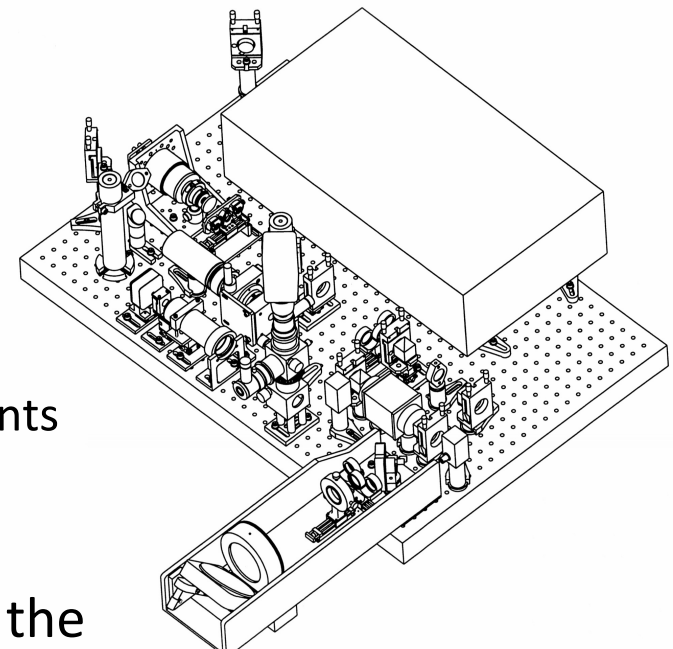


# What is the NGSLR Optical Bench?



- ◆ Laser Optical Head
- ◆ Adjustable Beam Expander for Divergence Control
- ◆ Risley Prism Assembly for Point Ahead Control
- ◆ Passive Transmit/Receive Optical Switch
- ◆ Liquid Crystal Rotator Assembly for Backscatter Control
- ◆ Automated Daylight Filter and Automated Iris for Noise Control
- ◆ Automated ND Filter Wheel Assembly for Ground Calibration
- ◆ High Quantum Efficiency (QE) MCP
- ◆ Star Calibration Camera and Optics
- ◆ Power Meter and Beam Profiler for Laser Energy and Beam Monitoring

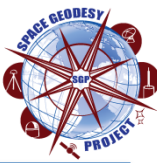
- ◆ Intended to be Fully Automated
  - No onsite operator required
- ◆ Initially designed for LAGEOS and below
  - No GNSS requirement
- ◆ Eye Safe Operations
  - ANSI Startle / Glare / Flash Blindness requirements not yet in place
- ◆ No Radar / Aircraft Monitoring system
- ◆ Risley prisms controlled by software to point the transmit ahead of receive
- ◆ Q-Peak Laser (MPV-2000)
  - 350 ps Pulse Width
  - 120  $\mu$ J Energy
  - 240 mW Power
  - 2 kHz Repetition Rate







# 1<sup>st</sup> Generation Optical Bench Design



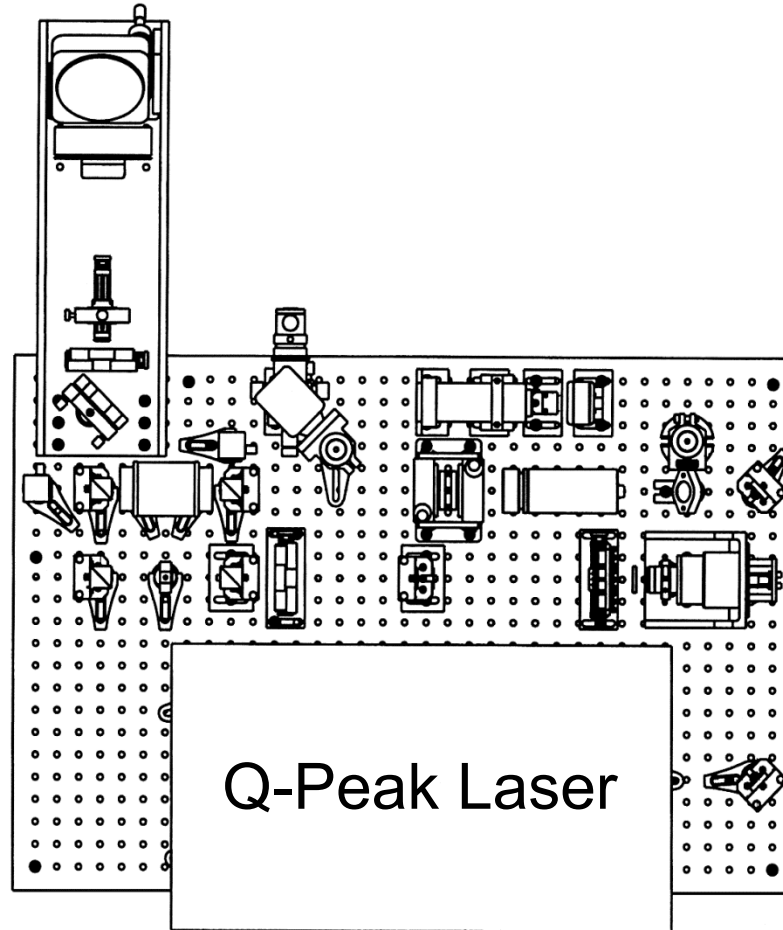
## Q-Peak Laser

350 ps Pulse Width

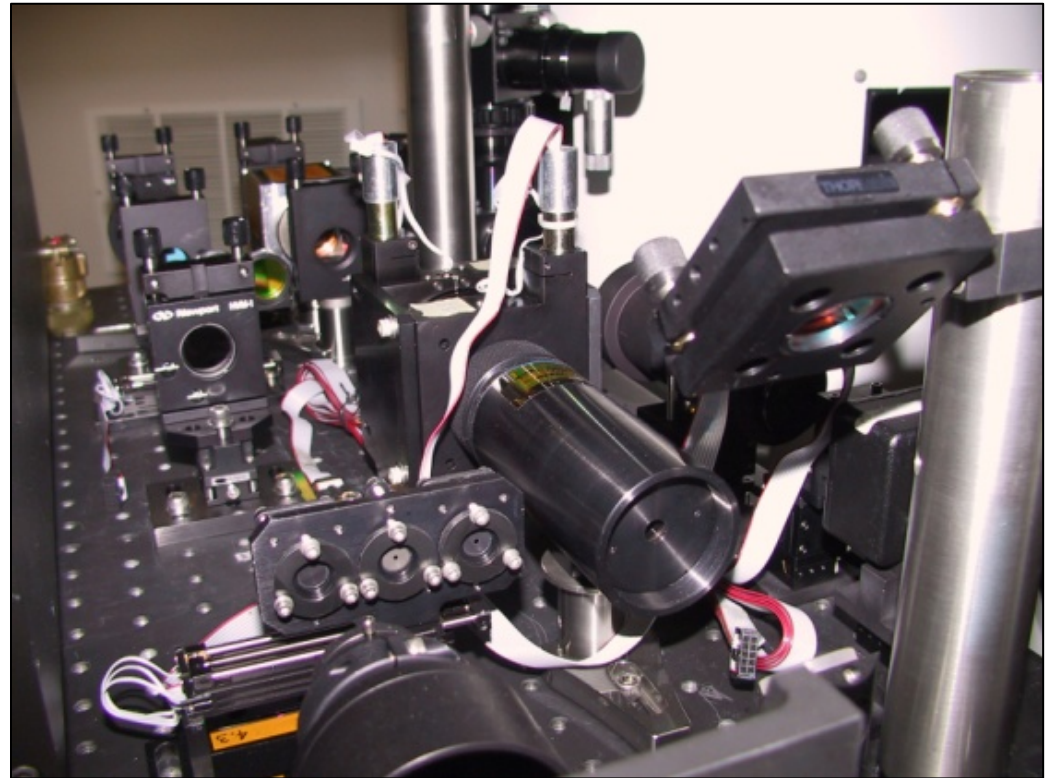
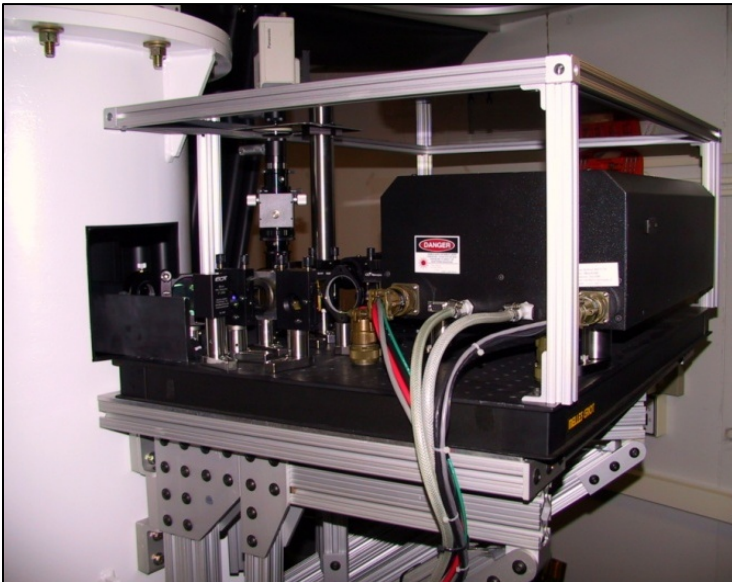
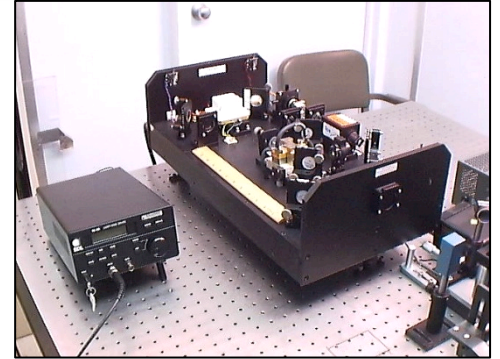
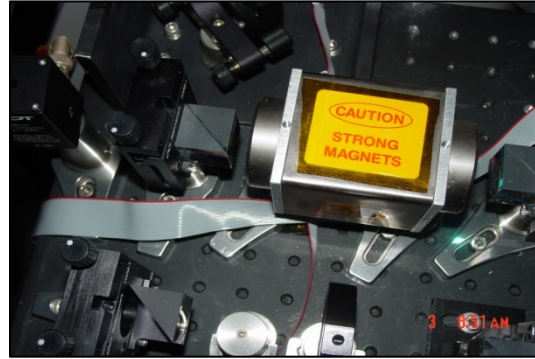
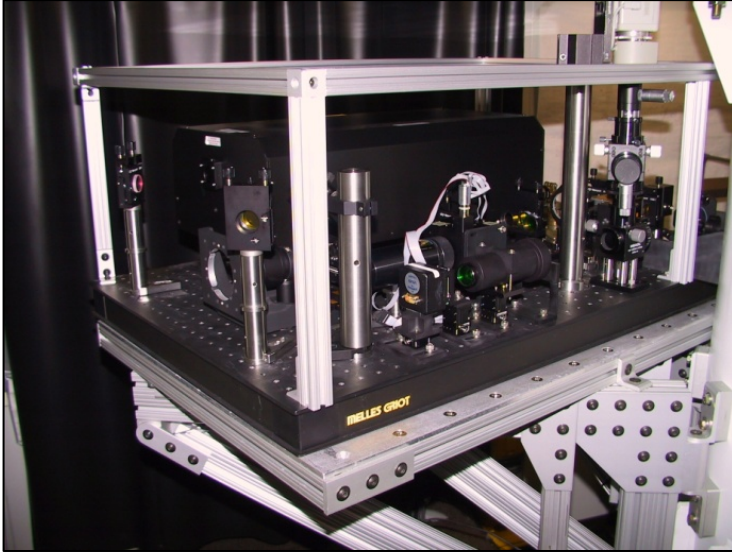
120  $\mu$ J Energy

240 mW Power

2 kHz Repetition Rate

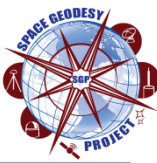


# 1<sup>st</sup> Generation Optical Bench





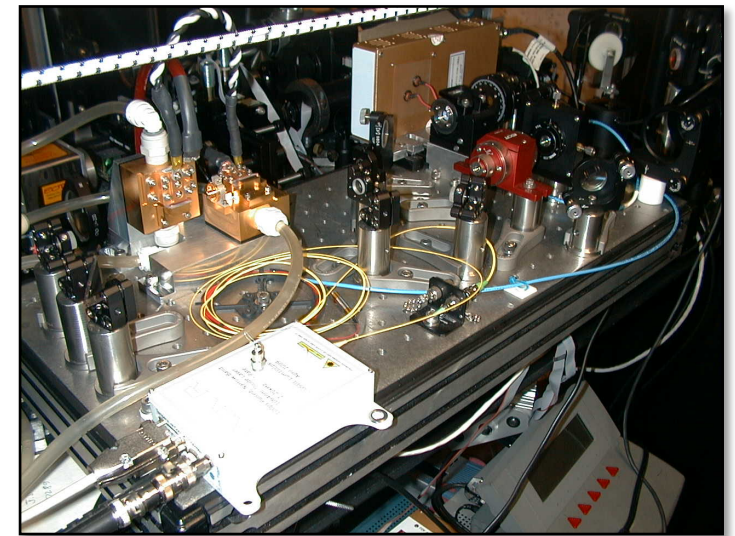
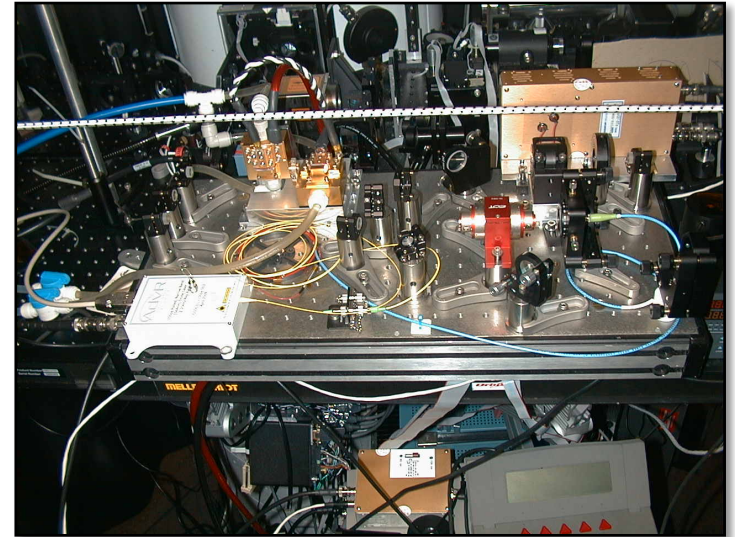
# 1<sup>st</sup> Generation Optical Bench Challenges



- ◆ Q-Peak power was slowly degrading over time
- ◆ Optical alignment unstable
- ◆ Configuration not optimal for efficient alignment
  - Components that needed minimal adjustment were closest and easiest to access
    - Laser
    - Star Calibration Leg
  - Components requiring frequent adjustment not very accessible
    - Receive Optical Leg: In the middle of the bench behind the laser
    - Transmit Optical Leg: T/R switch tucked behind the laser
- ◆ Beam paths were at different heights
  - Increased complexity of optical alignments
- ◆ Didn't allow for expansion
  - Relocation of ND attenuator and Beam block
  - Power Meter
  - Beam Profiler

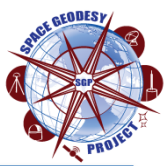


- ◆ NASA Laser (In House Build)
  - 200 ps Pulse Width
  - >1000  $\mu$ J Energy
  - >2 W Power
  - 2 kHz Repetition Rate
  - Variable laser energy including eye-safe capability
- ◆ GNSS requirement introduced
  - Nighttime and daytime tracking
  - Requires increased laser energy
- ◆ Safety standards tightened
  - ANSI Startle / Glare / Flash Blindness
- ◆ FAA requirement change
  - Operator required onsite
  - Aircraft avoidance / Laser interlock required
  - Laser Hazard Zones (LHZ) surrounding airports





# 2<sup>nd</sup> Generation Optical Bench Layout



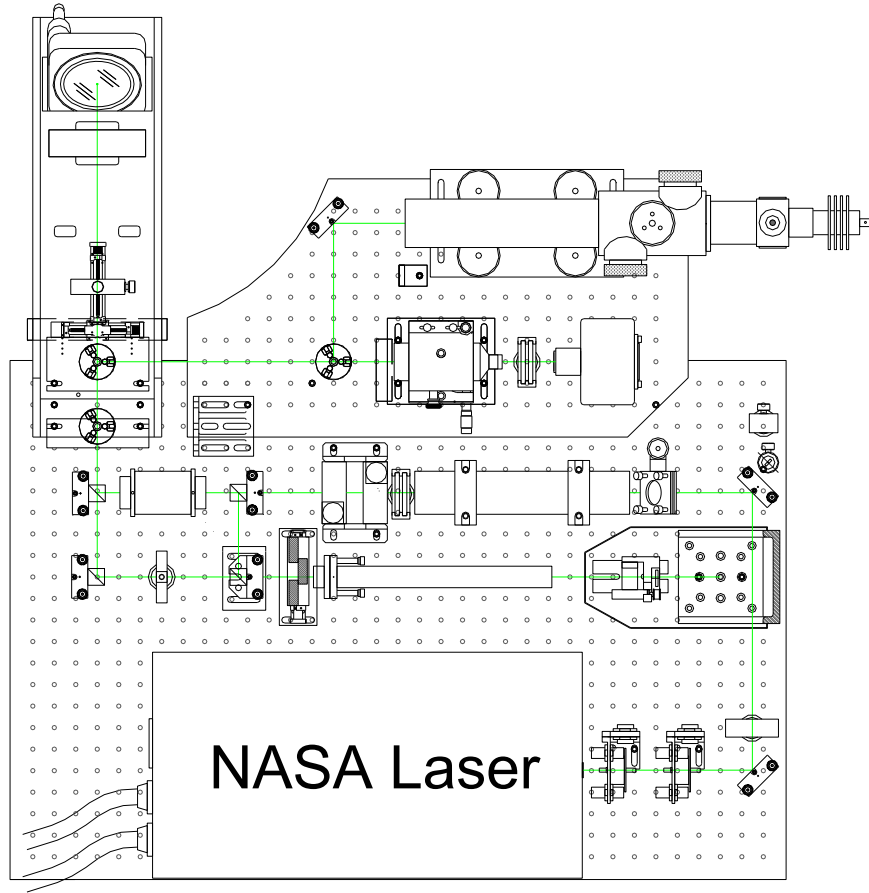
## NASA Laser

200 ps Pulse Width

>1000  $\mu$ J Energy

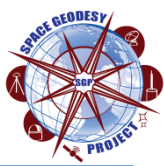
>2 W Power

2 kHz Repetition Rate





# 2<sup>nd</sup> Generation Optical Bench Challenges



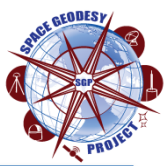
- ◆ NASA Laser worked well, but was not easily automated. Desired a COTS solution
- ◆ Higher power NASA laser (>1 mJ) began to cause distortion of the ND filters used during ground calibration
- ◆ Reaching limits of optical coatings. Originally specified for the 1<sup>st</sup> generation Optical Bench which was designed for low energy, low power, “wide” pulse laser
- ◆ With higher energy, backscatter into the receive path due to exposed optics became problematic
- ◆ Star Camera required the manual insertion of the pellicle, which introduced error into the alignment process
- ◆ Autocollimator required the manual insertion of a turning mirror, which introduced error into the alignment process
- ◆ Configuration still not optimal for efficient alignment
- ◆ Space on Optical Bench became cramped
  - Little room for expansion /modification
  - Power Meter
  - Beam Profiler

***Due to the limitations of this design and the daylight GNSS tracking requirement , a third generation design was needed***





# 3<sup>rd</sup> Generation Design Considerations



- ◆ COTS laser desired with increased laser energy, easily automated, shorter pulse width and increased stability.

### Q-Peak laser

350 ps Pulse Width  
120 μJ Energy  
240 mW Power  
2 kHz Repetition Rate



### NASA laser

200 ps Pulse Width  
>1000 μJ Energy  
>2 W Power  
2 kHz Repetition Rate



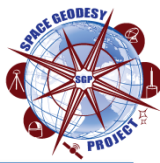
### Photonics laser

50 ps Pulse Width  
2,800 μJ Energy  
5.6 W Power  
2 kHz Repetition Rate

- ◆ High Power Optical Coatings
  - Original optics coated for a low energy laser and risked damage at higher power
  - Identify optics at risk and replace
- ◆ High Energy Beam Splitter (Etalon)
  - Permanently mount in the beam path to eliminate repeatability issues, replacing the pellicle
- ◆ Easy access to optical devices that require adjustment/alignment
- ◆ Light Tight Enclosures for both the MCP and Star Camera
- ◆ Alignment Aids
  - Irises and alignment targets
  - Alignment Laser
  - Beam Path Cameras
- ◆ Beam Profiler and Power Meter
  - Permanently mount to characterize laser performance during operation



# Further Design Considerations



## ◆ Automated Safety Features

- Development and Integration of the IO Chassis to control Beam Blocks, ND filters, and laser fire control

## ◆ Optical Bench Layouts

- Choose layout based on flexibility and ability to meet design criteria

## ◆ Custom Optical Table

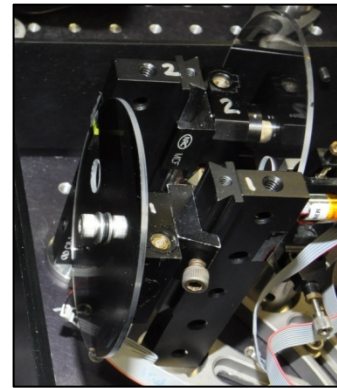
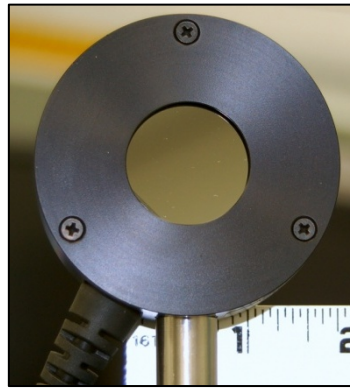
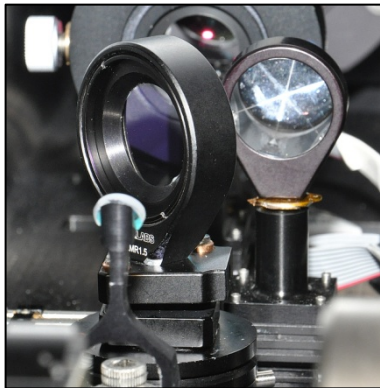
- Design to fit in the limited space of the shelter
- Allow for cleaner design

## ◆ Automation

- Eliminate system configuration changes between satellite tracking, ground calibration, and star calibration
- ND filters for Ground Calibration
- Iris in the receive path
- Shutters for MCP and Star Camera for equipment protection
- Daylight filter

**Over the past two years NGSLR has been upgraded to improve performance:**

- ◆ COTS Laser
- ◆ Liquid Crystal Rotator Assembly for Backscatter Control
- ◆ Etalon Beam Splitter
- ◆ Automated Iris for Noise Control
- ◆ Automated ND Filter Wheel Assembly for Ground Calibration
- ◆ Beam Profiler for Real-time Laser Beam Monitoring
- ◆ Power Meter for Laser Power



# Original Optical Bench Layout

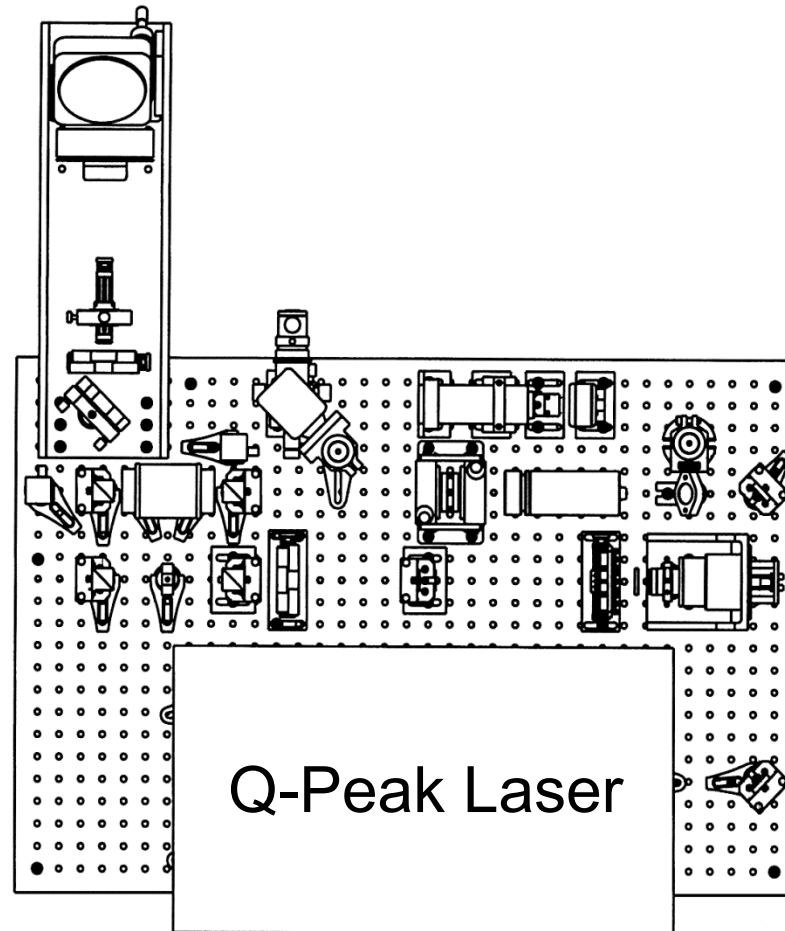
## Q-Peak Laser

350 ps Pulse Width

120  $\mu$ J Energy

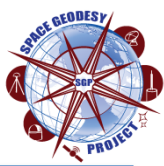
240 mW Power

2 kHz Repetition Rate





# 2<sup>nd</sup> Generation Optical Bench Layout



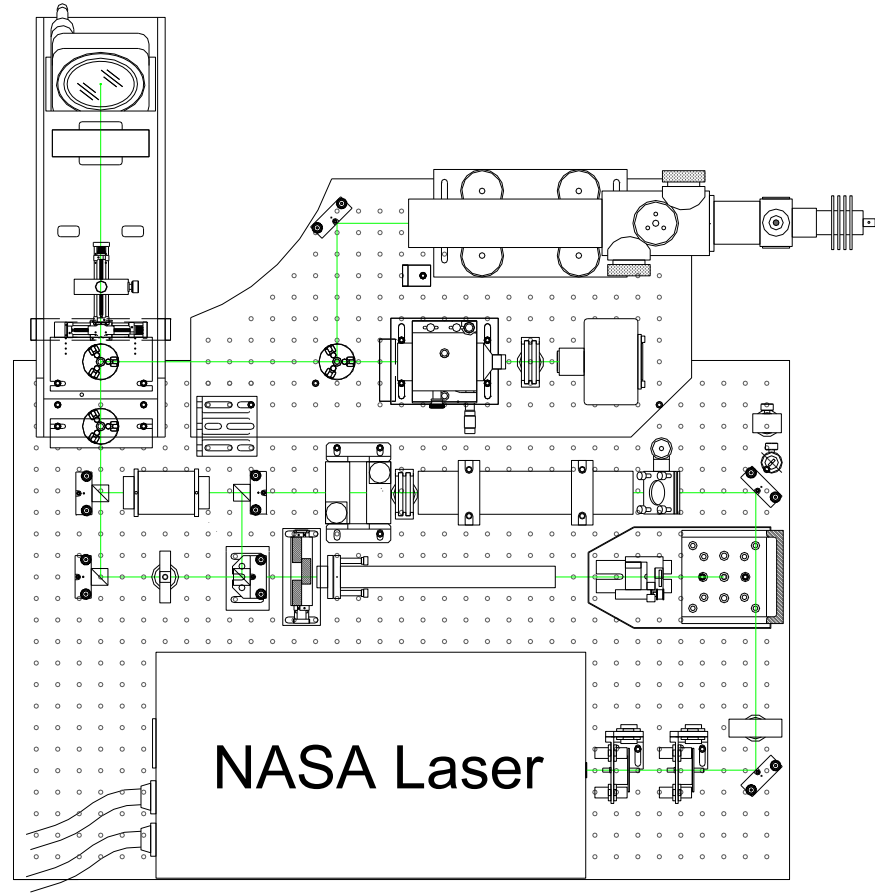
## NASA laser

200 ps Pulse Width

>1000  $\mu$ J Energy

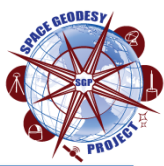
>2 W Power

2 kHz Repetition Rate





# 3<sup>rd</sup> Generation Optical Bench Layout



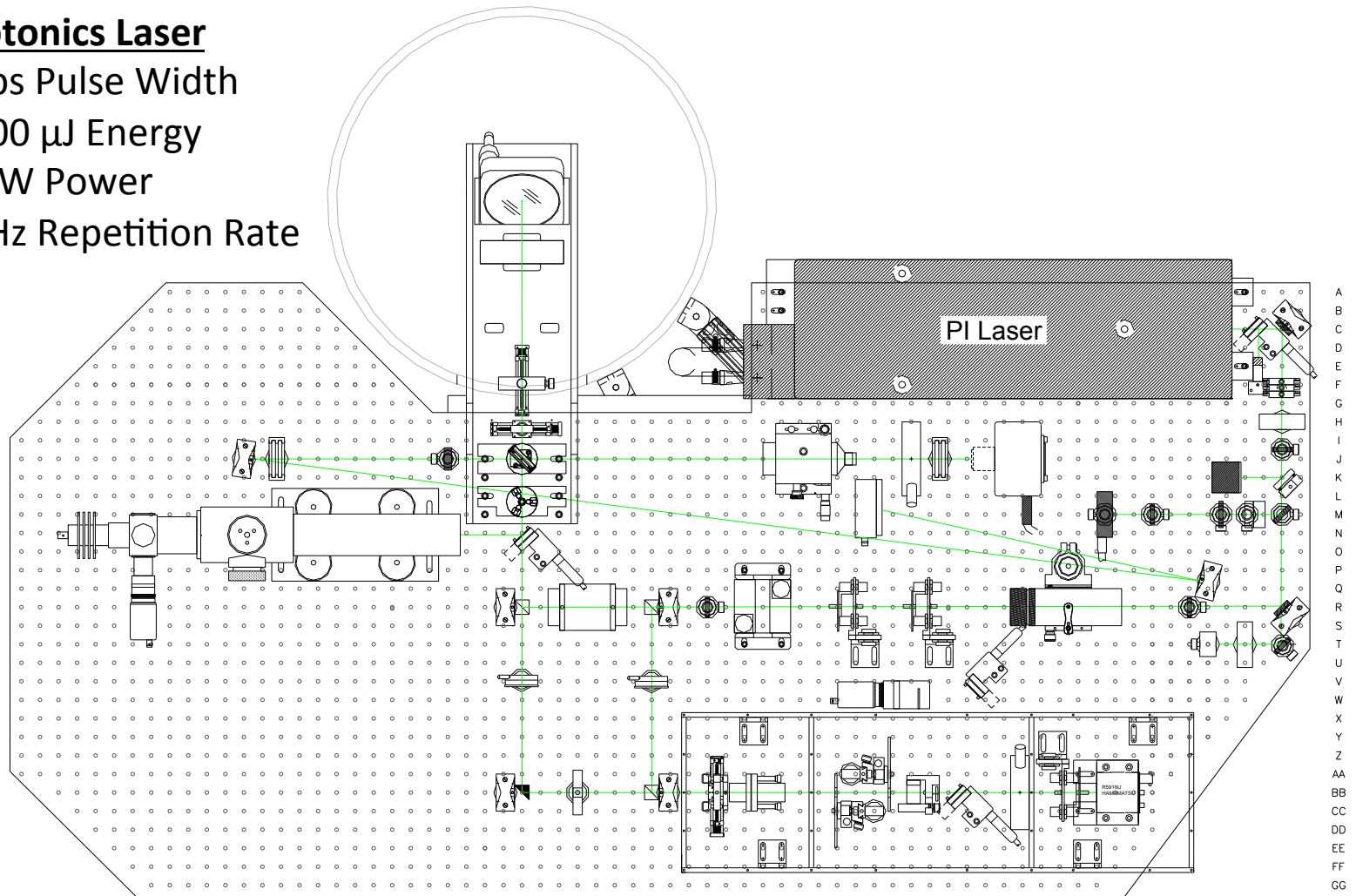
## Photonics Laser

50 ps Pulse Width

2,800  $\mu$ J Energy

5.6 W Power

2 kHz Repetition Rate



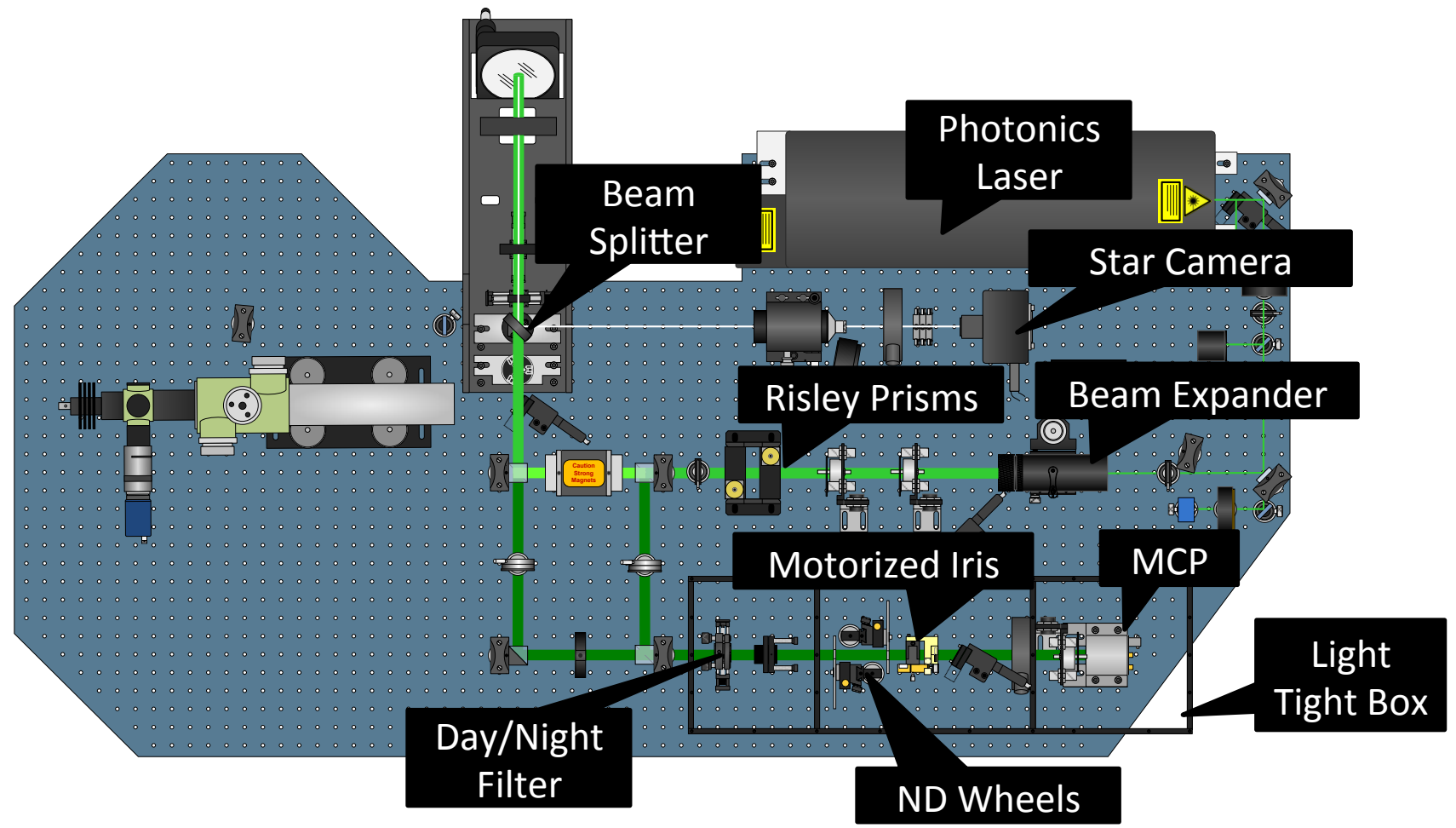
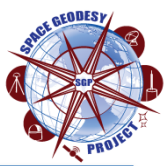
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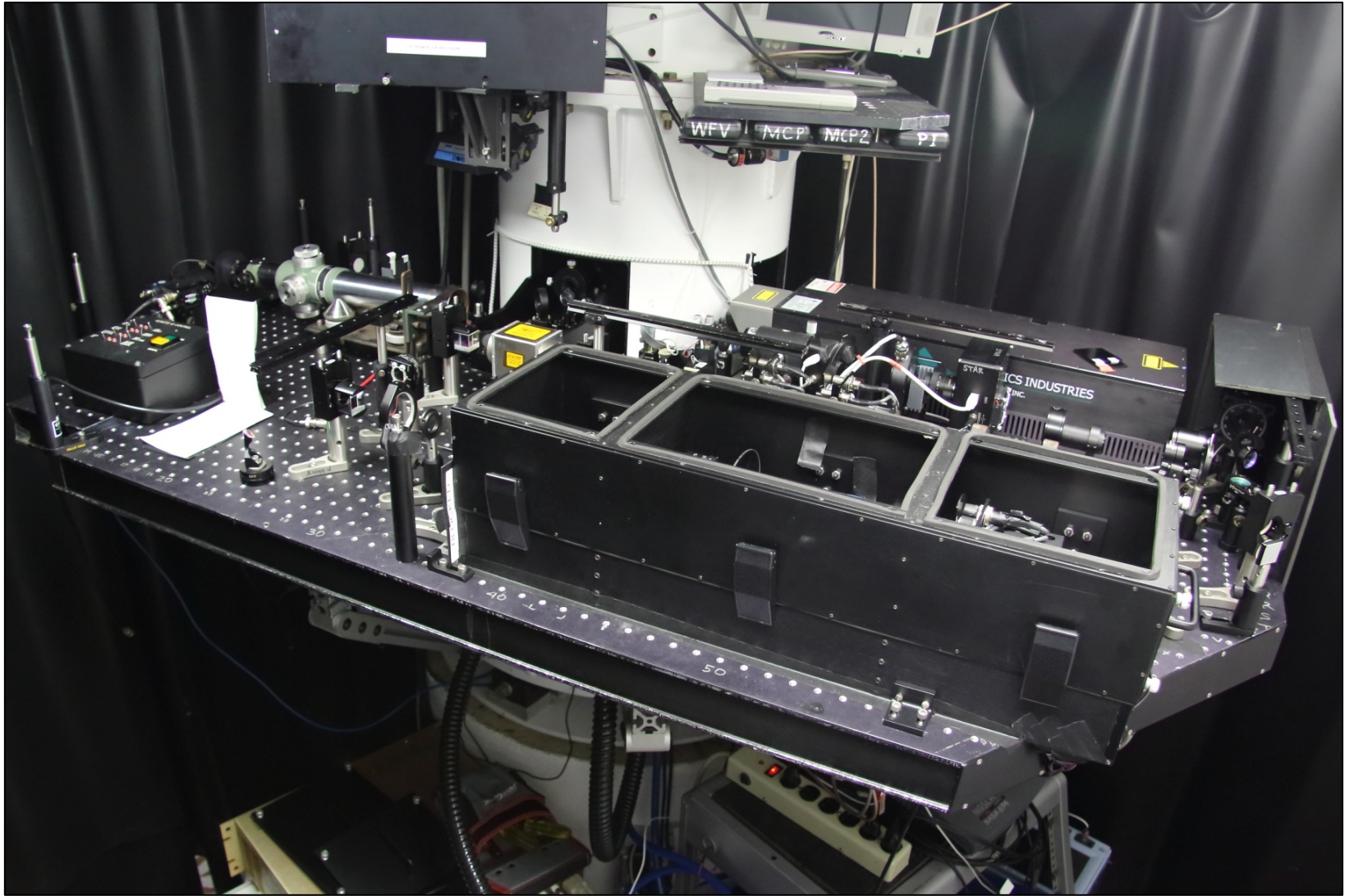
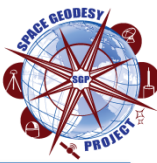


# 3<sup>rd</sup> Generation Optical Bench





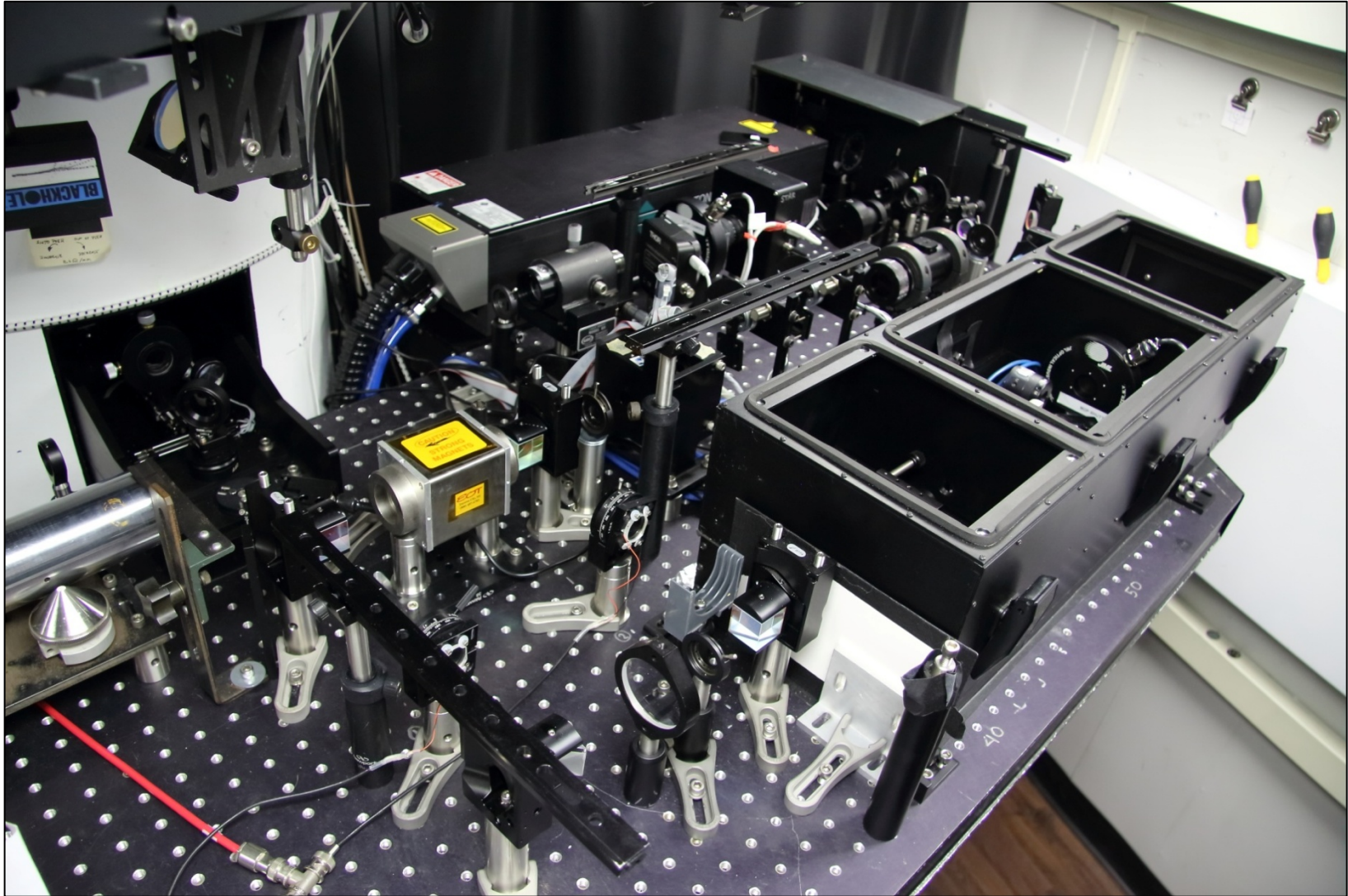
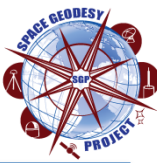
# 3<sup>rd</sup> Generation Optical Bench





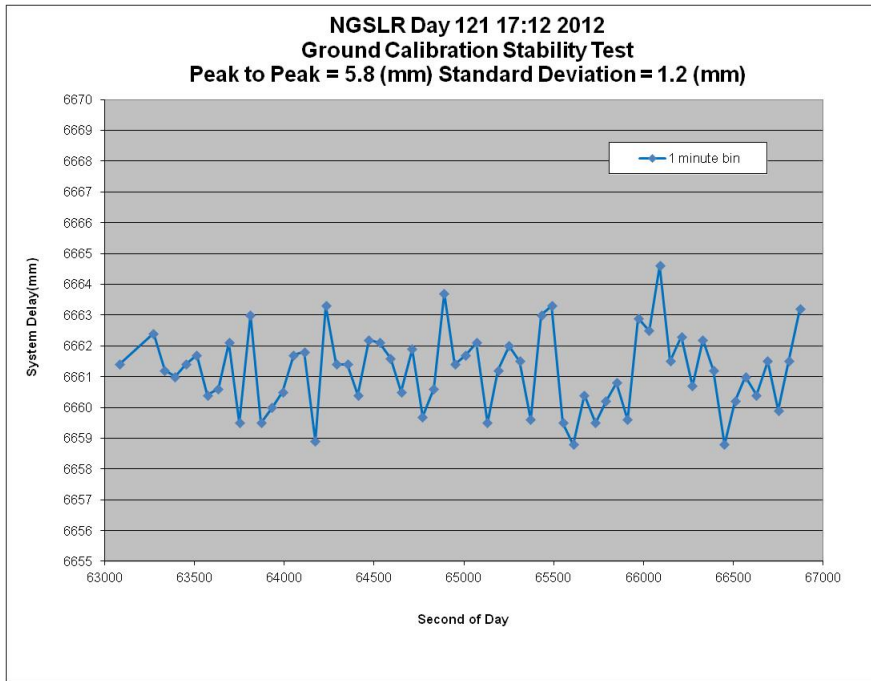
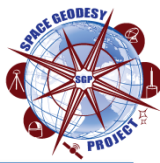


# 3<sup>rd</sup> Generation Optical Bench

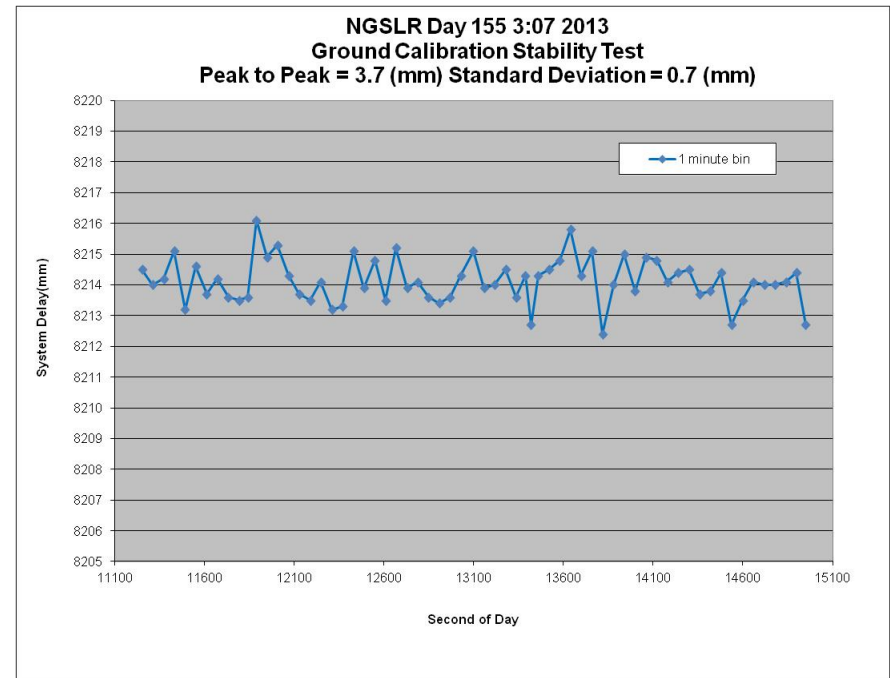


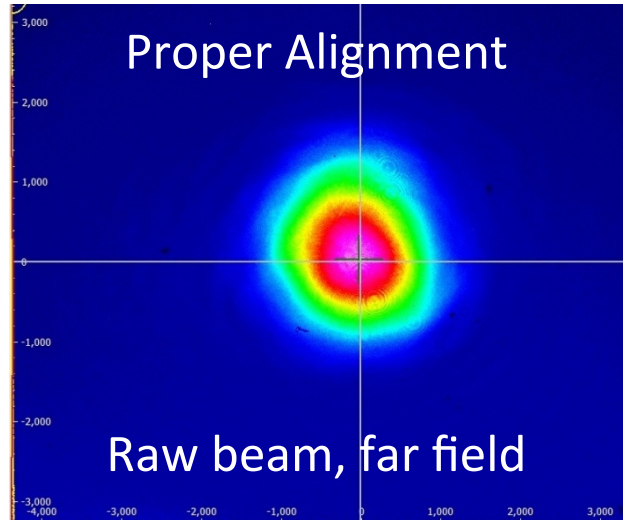
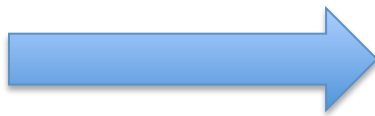
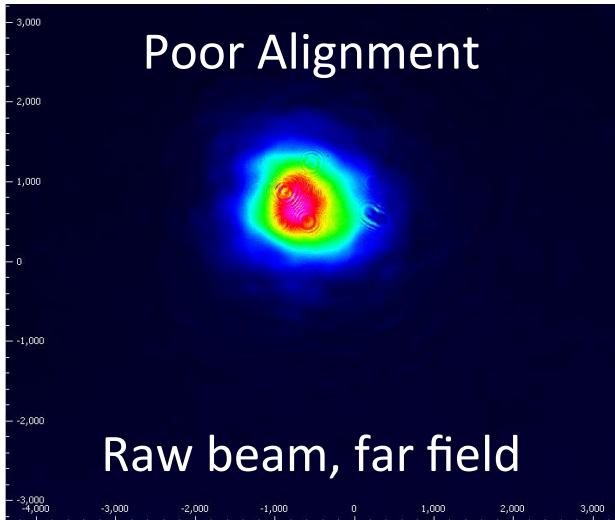


# Ground Calibration Results

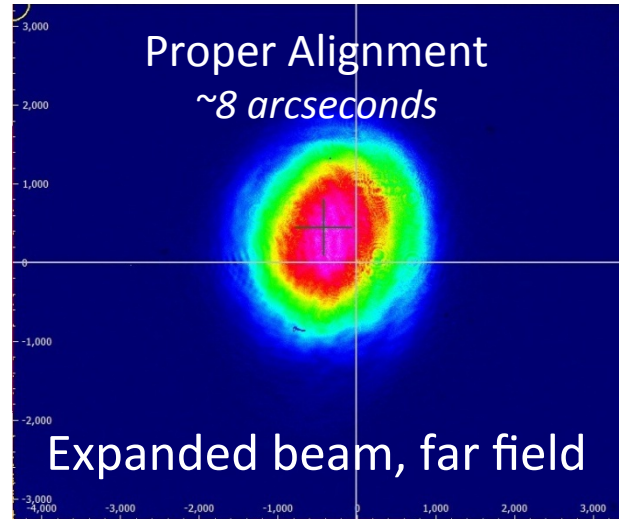
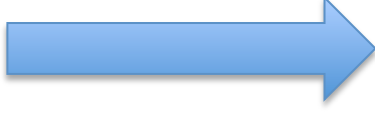
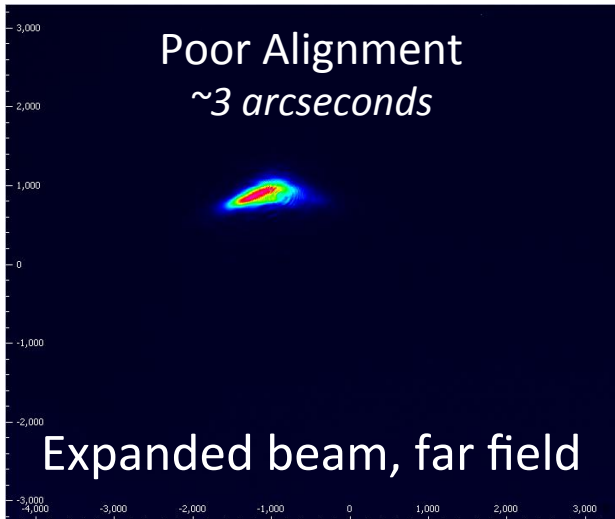


	Before	After
Peak to Peak	5.8 mm	3.7 mm
Standard Deviation	1.2 mm	0.7 mm



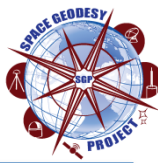


Beam expander alignment is critical to maintain beam shape in the far field





# Lessons Learned and Performance Improvements



- ◆ New COTS laser
  - Photonics Industries laser proved relatively stable
  - Software controlled for turn on and power level setting
- ◆ New alignment aids and mounting for the Beam Expander
  - Beam Profiler most useful tool for far field optical alignment
  - Hinge system under Beam Expander allows the expander to be moved in and out of the beam path to aid the alignment process
  - New mounts allows fine adjustment in x and z axis, as well as tip and tilt
- ◆ Overall improved alignment process, less complex
  - Optical mounts easily accessible
  - Permanently mounted irises allow quick verification of alignments
- ◆ Alignment of the Optical Bench proved stable. Alignment not required during collocation between May 29th - July 5<sup>th</sup>
- ◆ Ground calibration stability improved
  - RMS < 1 mm for up to 2 hour periods





*Thank You!*

