A photograph of the Keck II telescope on Maunaloa, Hawaii, at night. The telescope is illuminated by two bright yellow laser beams that extend into the dark sky. The Milky Way galaxy is visible in the background, and the foreground shows the dark, rocky terrain of the mountain. The text "Keck II Next Generation Laser System" is overlaid in white, bold font in the center of the image.

Keck II Next Generation Laser System

November 16, 2014

Ethan Tweedie Photography

Project Background

- 2012: completion of the Free Space Transport in Keck I with the LMCT laser
- 2013-2014: Center Launch System (CLS) for Keck II (dye laser)
- Next Generation Laser (NGL) system
 - Funded by GBMF and WMKF
 - Replacement of the dye laser with the TOPTICA laser
 - TOPTICA laser developed with consortium (ESO, WMKO, TMT)
 - Integration with the completed CLS
 - Preparation for future Next Generation Adaptive Optics System (NGAO) with three lasers

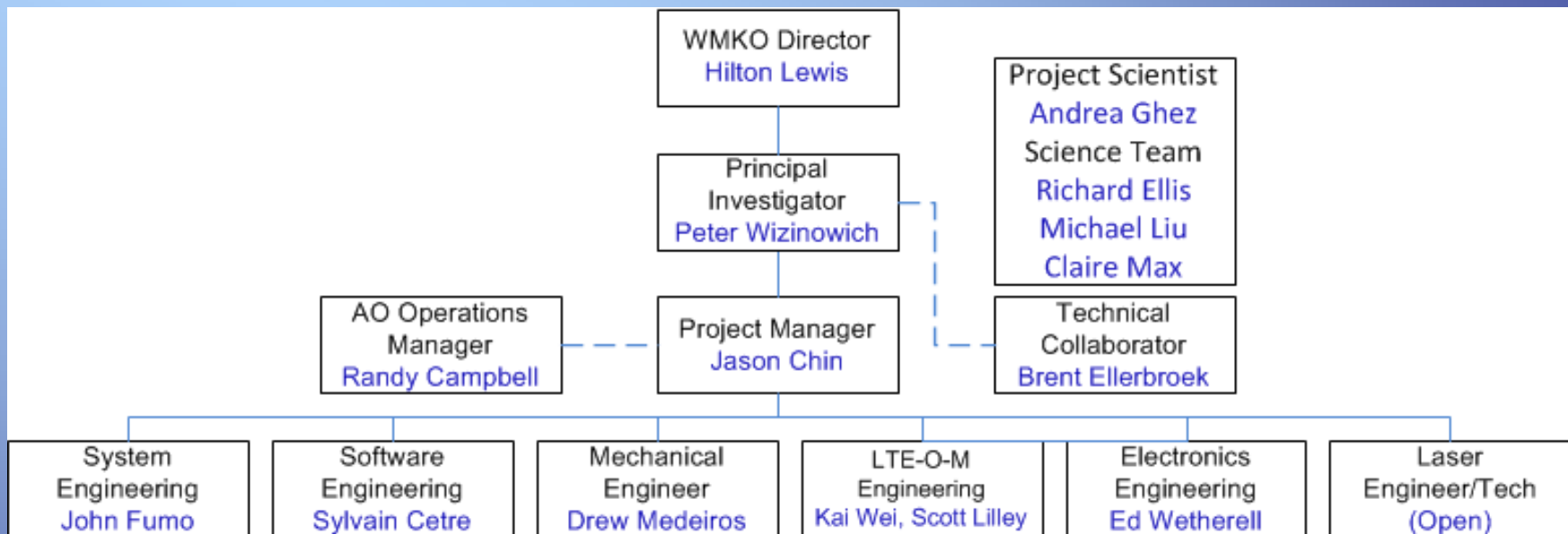
Schedule

| Milestone | Date |
|---------------------------------------------|---------------------------|
| System Design Review | April 26, 2013 |
| Preliminary Design Review | March 25, 2014 |
| Detailed Design Review | November 03, 2014 |
| Decision date to decommission dye laser | February 01, 2015 |
| Integration of subsystems on the summit | February – September 2015 |
| Decommissioning of dye laser | September 2015 |
| Installation and commissioning of new laser | September 2015 – Jan 2016 |
| NGL system science | February 2016 |

- Full Scale Development Phase (Nov 2014 – Apr 2015)



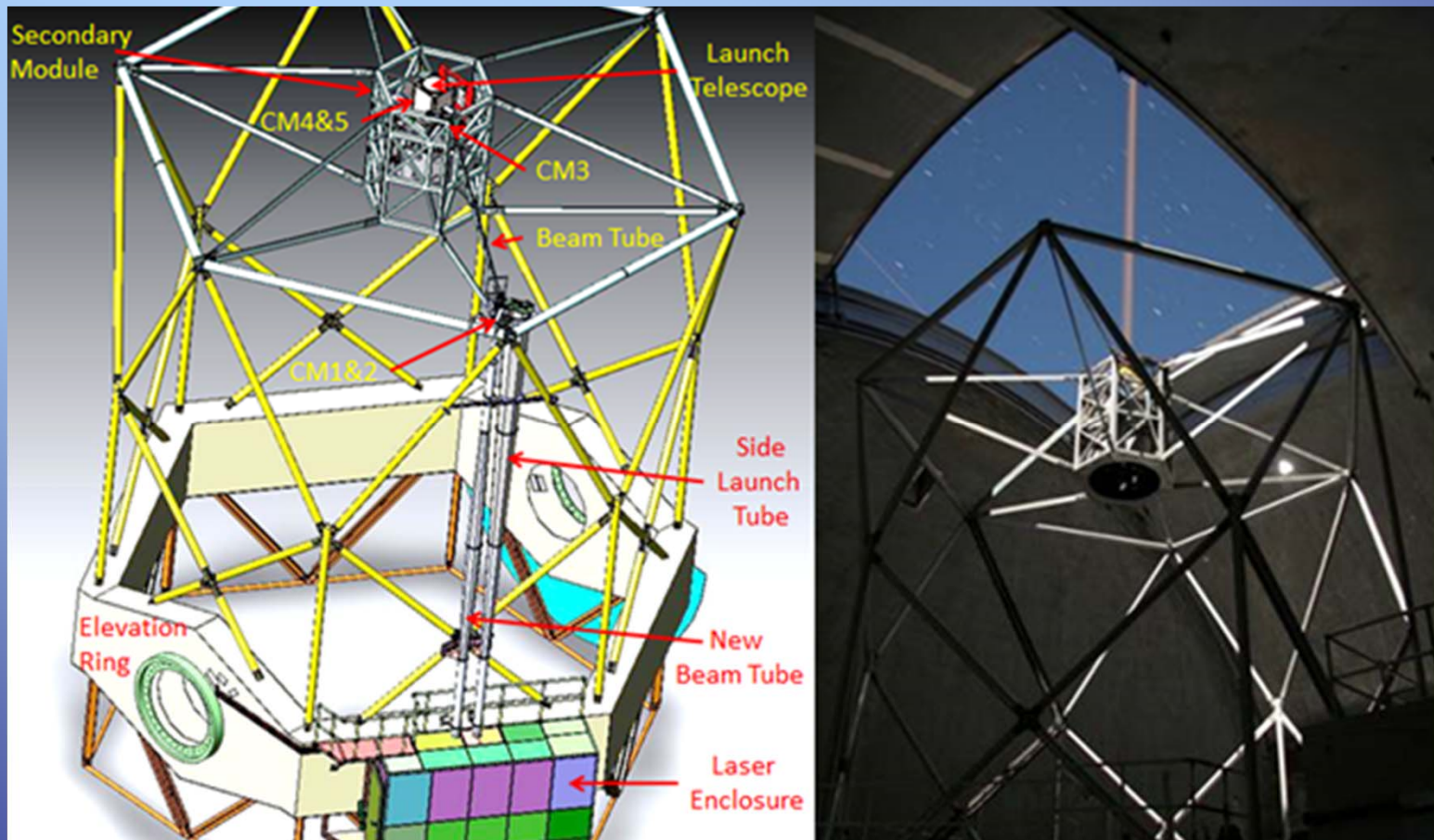
Project Team



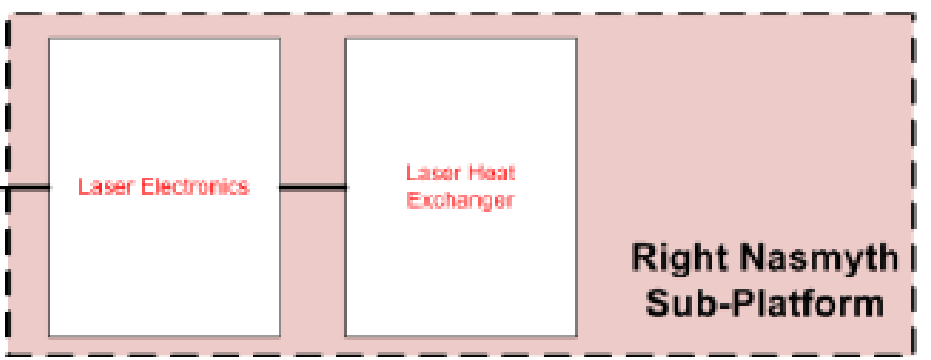
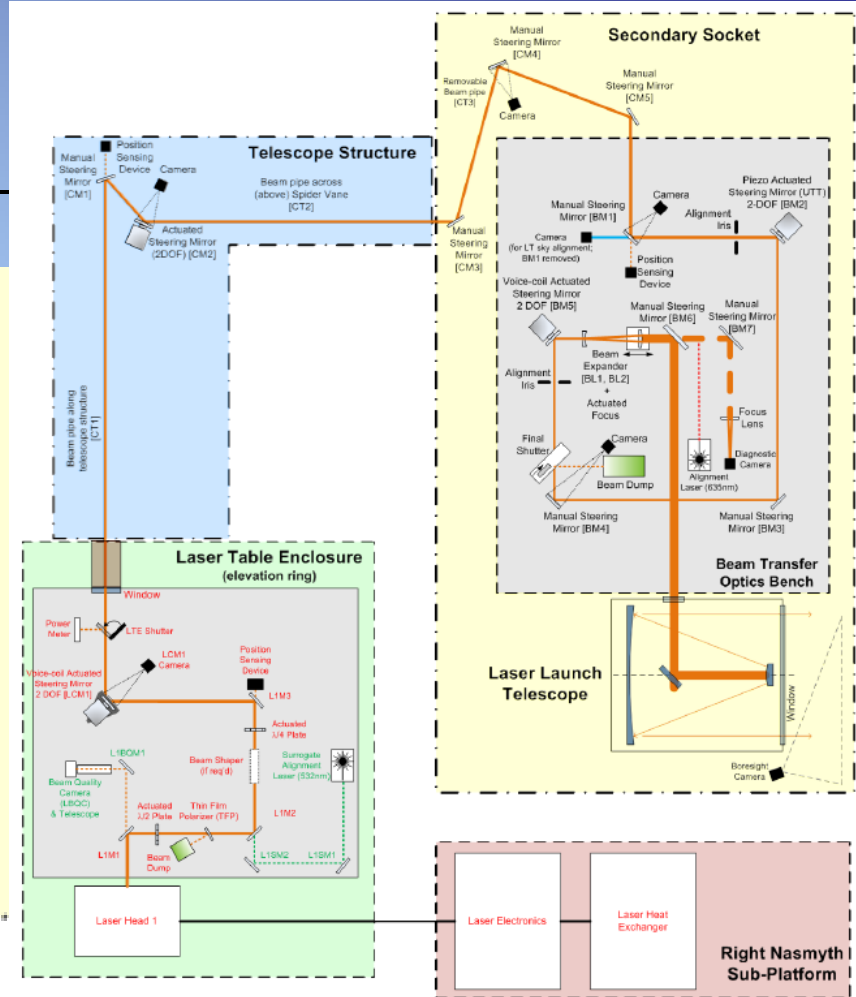
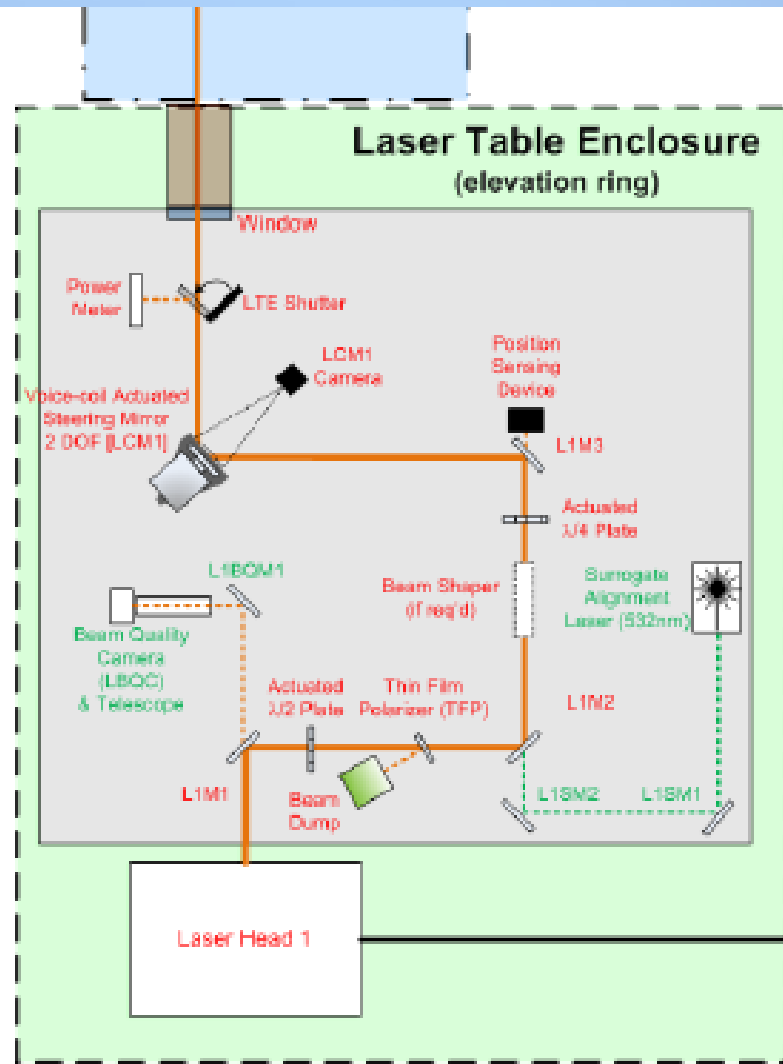
System Overview



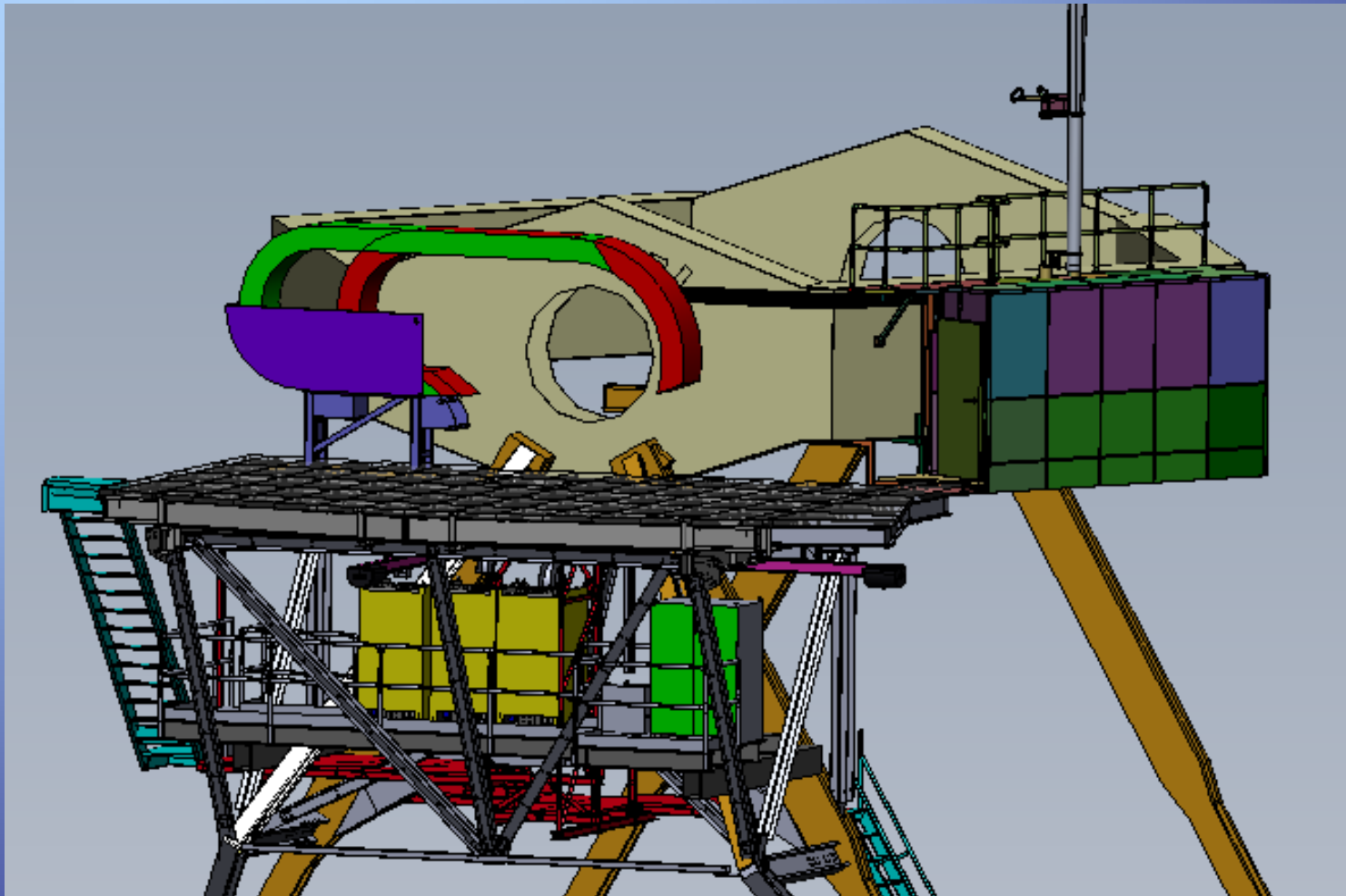
Center Launch System



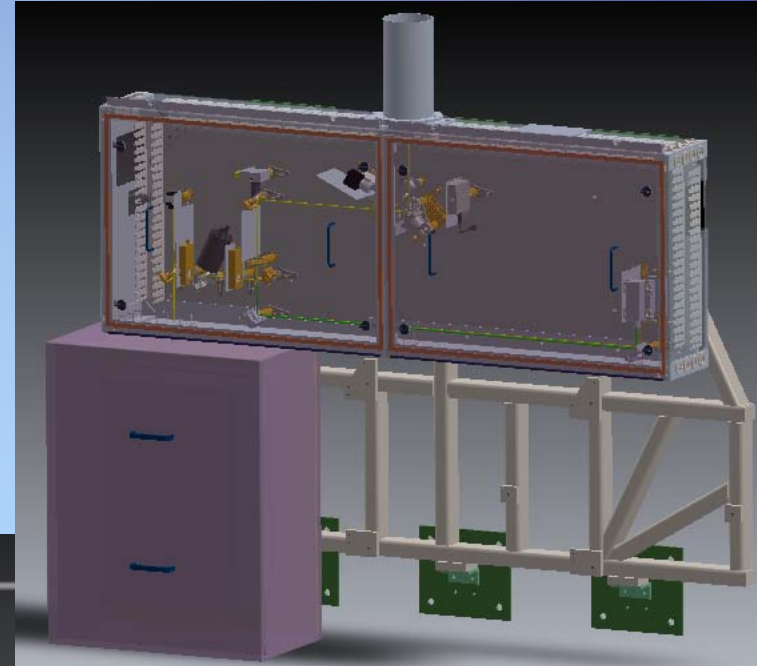
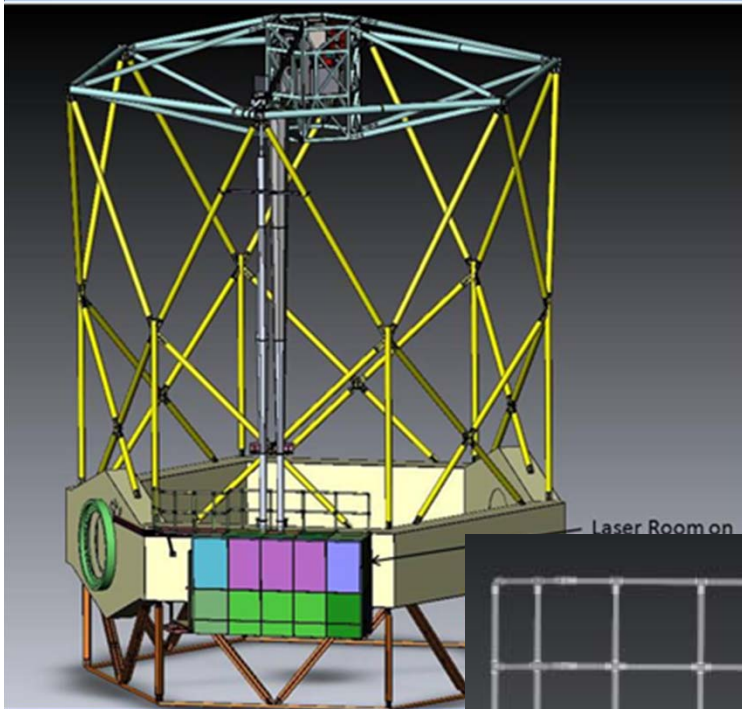
NGL System Layout



Laser Platform



Laser Table Enclosure



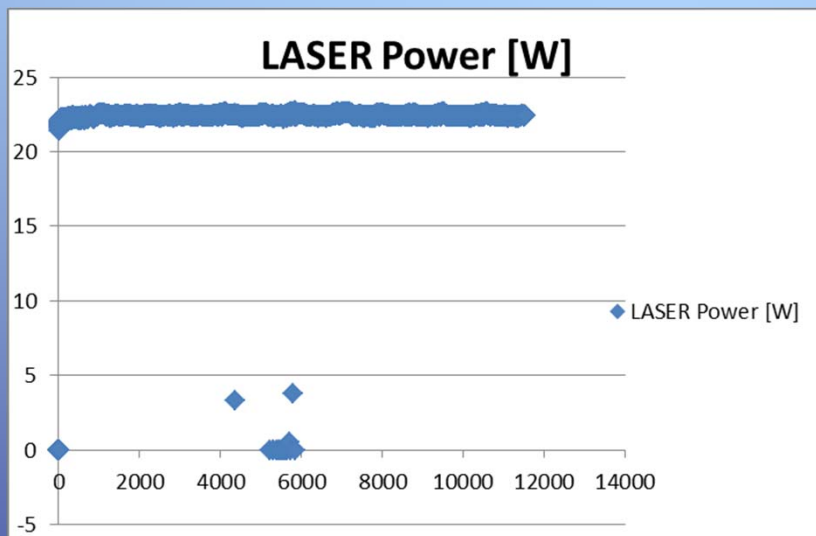
Toptica Laser System

- Continuous wave (CW); 20W with optical repumping of D2b.
- Diode pump fiber laser with second harmonic generation
- Ability to detune off wavelength
- Fast startup (<40 minutes with calibration)
- Continuous and manual health checks to monitor performance
- Efficiency; low power usage compared to existing laser systems
- Remote pumping (WMKO) vs. local pumping (ESO)
 - Requires slightly 8% more power from diodes

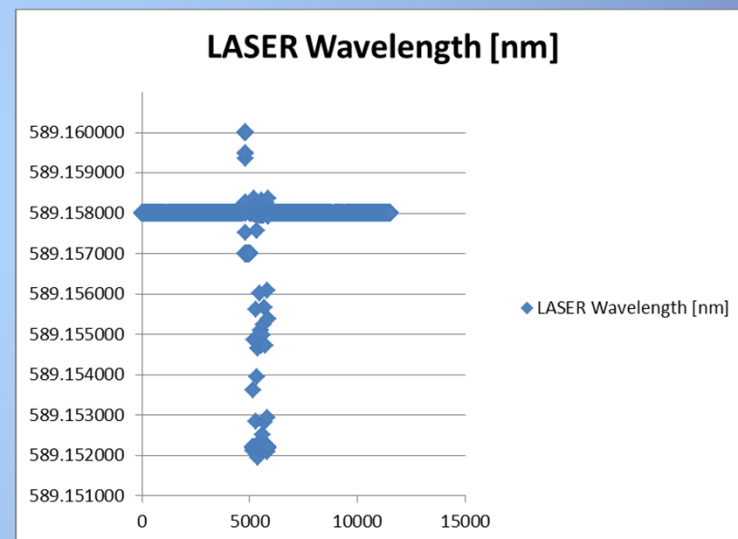


Toptica Laser System Performance

- Power and wavelength extremely stable
- $<2\%$ change in power due to elevation changes



Fluctuations during detuning



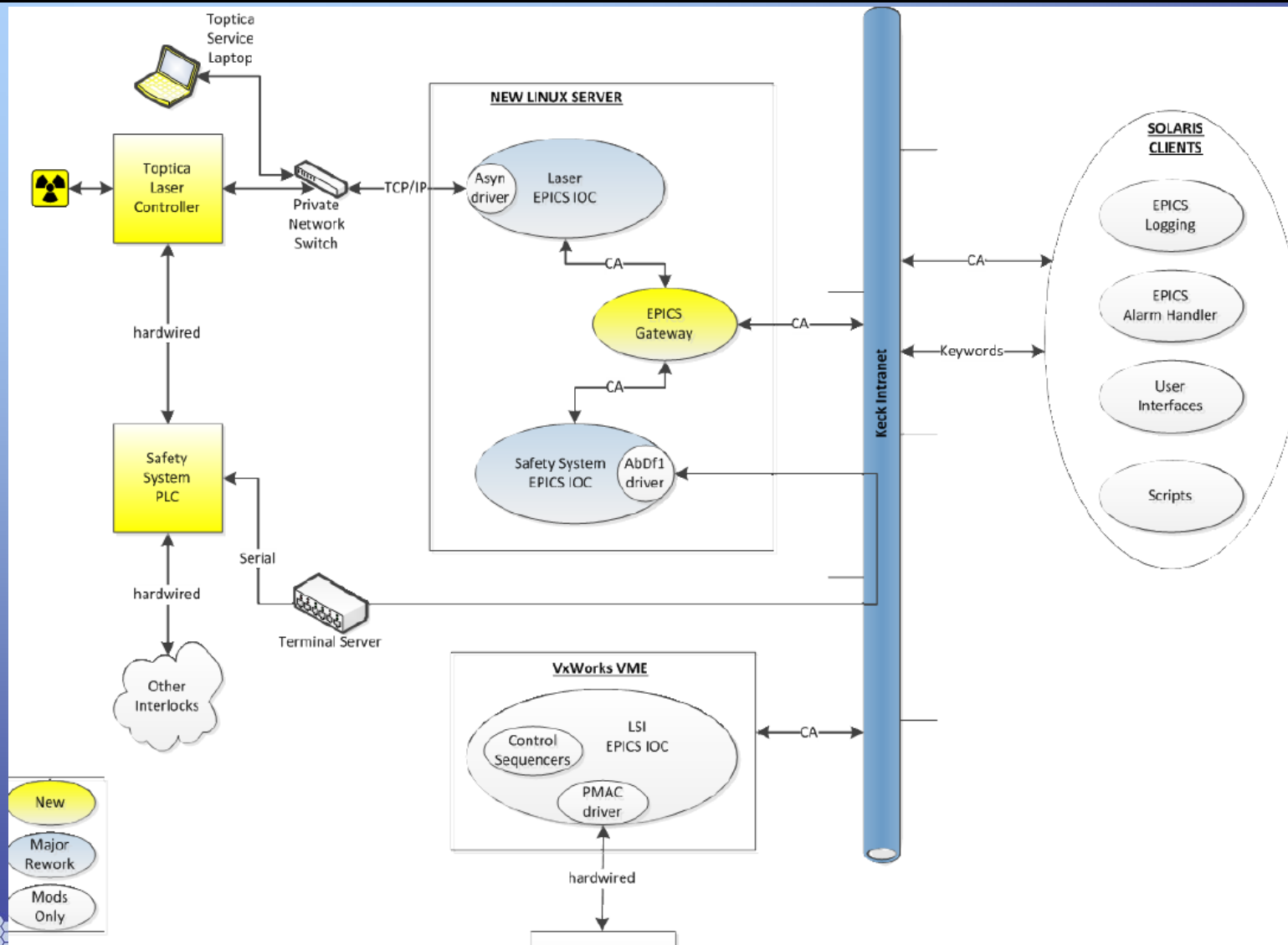
Fluctuations due to manual wavelength changes



Toptica Laser System Status

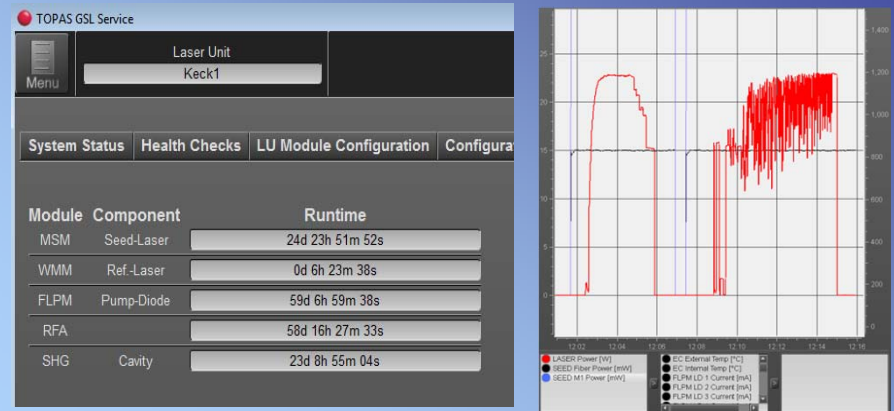
- Factory Acceptance Testing completed in 09/2014
 - Sufficient redundancy in system; power supply and diodes
 - Failed diodes did not impact performance
- Laser delivered to WMKO in 10/2014
- Headquarters Acceptance Testing
 - Initial setup and tests completed 11/14/2014 (TOPTICA/MPBC personnel)
 - Performance tests; Nov 2014 to Jan 2015
 - Environmental testing; 0°C glycol and <10°C room
 - Put time on system and diodes
 - Simulate night time observing

Laser System Control



Laser Service Laptop

- Ability to control laser
- Plot performance
- Trigger health checks
- Load new firmware
- Log data
- Troubleshooting
- Communicates with internal subsystems
- Internal diagnostics, reference laser, wavemeter, FPI
- Interlocks viewing
- Thresholds
- Run time
- Version control



TOPAS GSL Service

Menu Laser Unit Keck1

System Status Health Checks LU Module Configuration Configura

System Status

OP State: STANDBY About Transition 2014-09-09T11:42:52

Target OP State: STANDBY

Transition Status: 0 s

Status: -2004 Failure: -2004 Parameter plcm:hyd:spm-flow is below failure range [1.000000/min - inf/min] 0.001186/min (COOLING SYSTEM)

Wavelength & Power

Wavelength: 589.157999 nm Stable

Detuned: Enabled

Power: -0.00 W

Power SP: 22.8 W

Repumper

Amplitude: % Acquire

Amplitude SP: 10 %

Shutter

Open/Close Open Delay: 5000 ms

Status: closed

Interlock

- Output Shutter Permission: Emission on
- Safety status
- Leakage Error - Heat Exchanger
- Leakage Error - Laser Unit
- Heat Exchanger Fault
- Error Control Software
- Laser Unit Fault
- LH cover open
- Cabinet door open

Status History

2014-09-09T11:41:56:583Z Failure: -2005 Parameter plcm:hyd:electronic:cabinet flow is below failure range [4.800000/min - inf/min] -0.002128/min (COOLING SYSTEM)

2014-09-09T11:41:06:606Z Failure: -2004 Parameter plcm:hyd:spm-flow is below failure range [1.000000/min - inf/min] 0.003336/min (COOLING SYSTEM)

2014-09-09T11:42:30:894Z Ok (Reset)

2014-09-09T11:42:42:662Z Failure: -2014 Heat Exchanger leakage detected (COOLING SYSTEM)

2014-09-09T11:42:42:643Z Failure: -2001 Leakage detected (COOLING SYSTEM)

2014-09-09T11:42:44:721Z Failure: -2005 Parameter plcm:hyd:electronic:cabinet flow is below failure range [0.800000/min - inf/min] -0.001958/min (COOLING SYSTEM)

2014-09-09T11:42:44:723Z Failure: -2004 Parameter plcm:hyd:spm-flow is below failure range [1.000000/min - inf/min] 0.001186/min (COOLING SYSTEM)

Transition History

Operation state READY

Transition from READY to STANDBY: SHG - Transition from READY to STANDBY

Transition from READY to STANDBY: SHG - Operation state STANDBY

Transition from READY to STANDBY: FLPM - Transition from READY to STANDBY

Transition from READY to STANDBY: FLPM - Operation state STANDBY

Transition from READY to STANDBY: SEED - Transition from READY to STANDBY

Transition from READY to STANDBY: SEED - Operation state STANDBY

Transition from READY to STANDBY: WMM - Transition from READY to STANDBY

Transition from READY to STANDBY: WMM - Operation state STANDBY

Operation state STANDBY - Failure in laser status

TOPAS GSL Service

Menu Laser Unit Keck1

System Status Health Checks LU Module Configuration Configuration Management Runtimes Supervision

| LU Label | Serial # | Installation date | Hardware-Version | Firmware-Version |
|----------|----------------|-------------------|------------------|------------------|
| MSM | MSM_0005 | 29 Nov 2013 | | 2.1.2 |
| WMM | WMM_0006 | 29 Nov 2013 | | 2.1.2 |
| FLPM | FLPM_0007 | 29 Nov 2013 | 4.5 | |
| PLCM | PLCM_0004 | 29 Nov 2013 | 4.5 | 101427_24_0.2.5 |
| FLPS | FLPS-1411-3070 | 29 Nov 2013 | | |
| FLPM | FLPM-1411-3069 | 29 Nov 2013 | YFLP-100-1200 | 0.1.0.0 |
| RFA | RFA-1411-3068 | 29 Nov 2013 | RFA-P-36-1170R | |
| SHG | SHGM_0006 | 29 Nov 2013 | | 2.1.2 |
| HYD | HYD_0007 | 29 Nov 2013 | | |

Save Load from file

TOPAS GSL Service

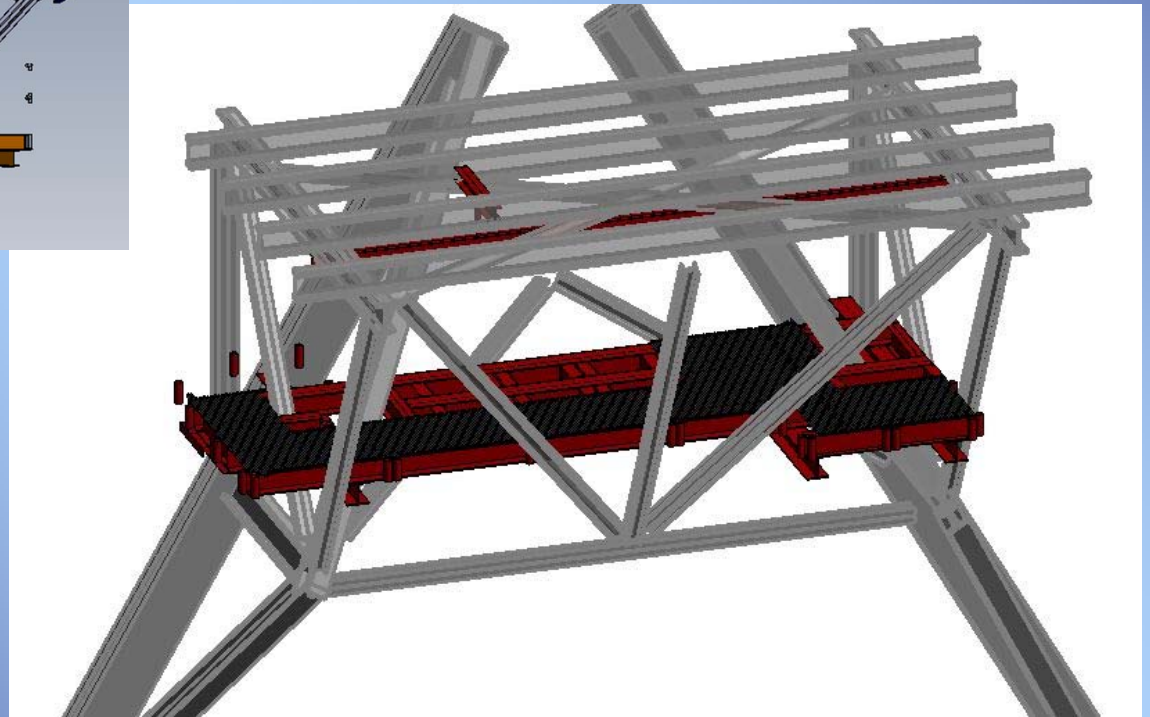
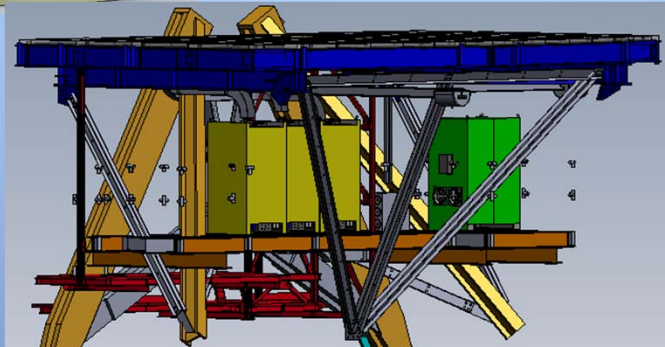
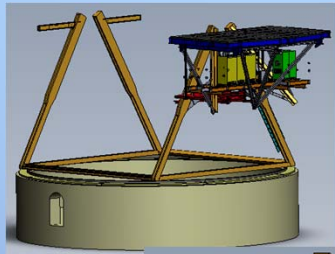
Menu Laser Unit Keck1

Cooling Status Module Temperatures Calibration

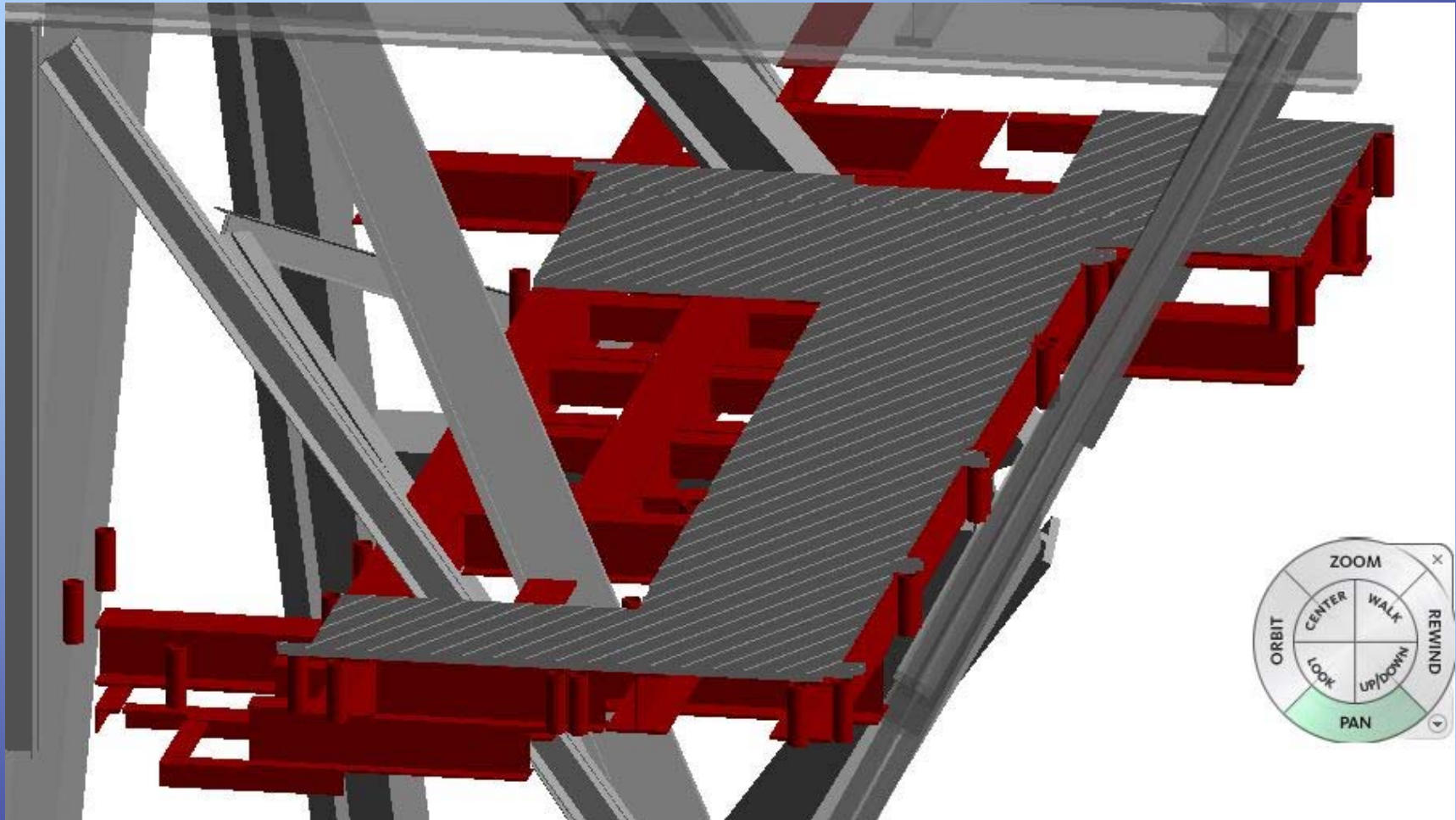
| Modules | FLPM Cold Plates | FLPM Pump Combiners |
|----------------------|------------------|---------------------|
| WMM: 17.2 °C | 1: 25.2 °C | 1: 19.6 °C |
| Seed: 17.6 °C | 2: 19.9 °C | 2: 17.8 °C |
| SHG: 15.7 °C | 3: 23.2 °C | 3: 20.3 °C |
| PLCM: 18.0 °C | 4: 21.9 °C | 4: 17.9 °C |
| EC Internal: 18.6 °C | | 5: 20.3 °C |
| EC External: 20.3 °C | | 6: 18.2 °C |



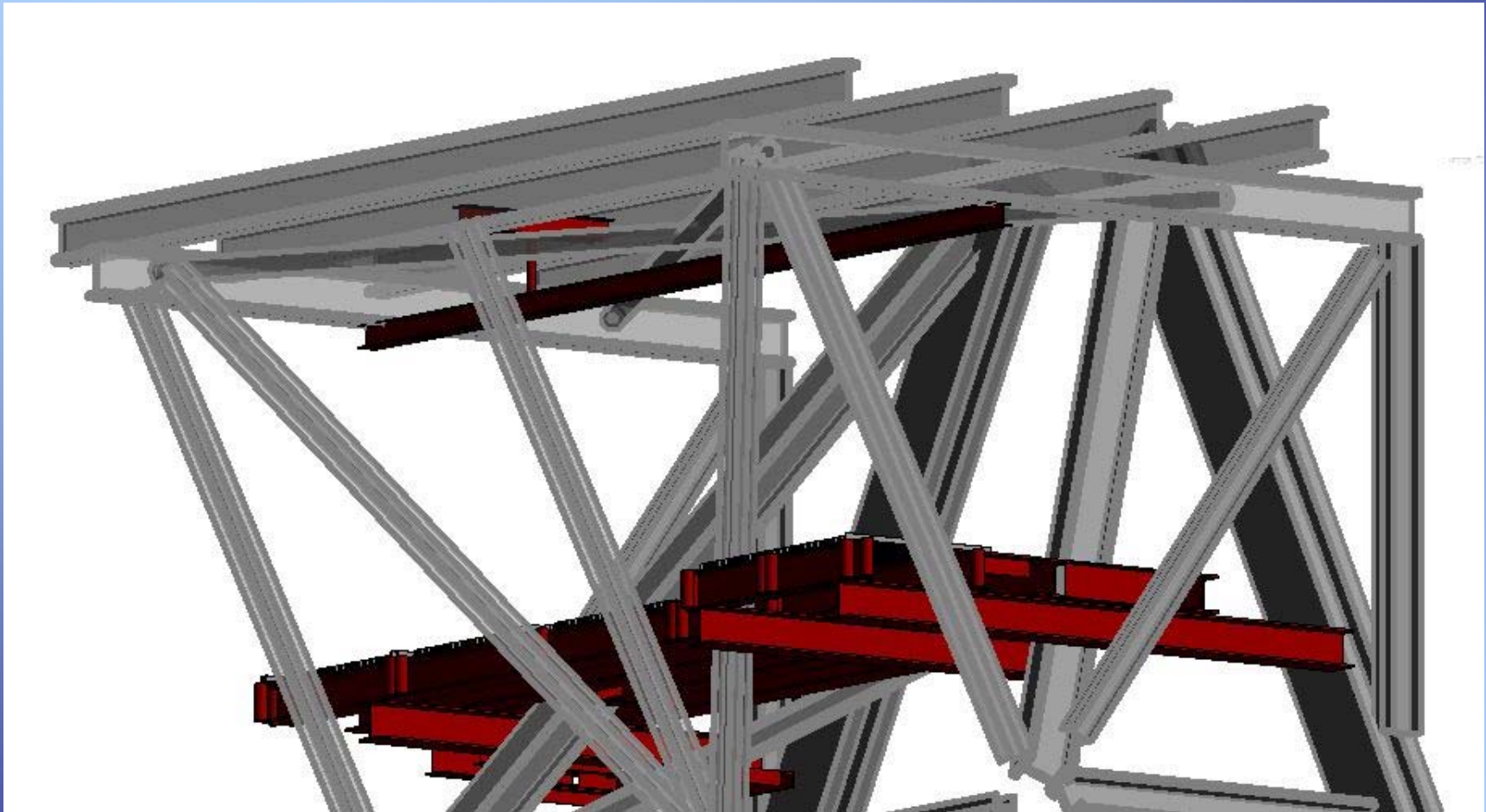
Platform Layout



Platform Layout

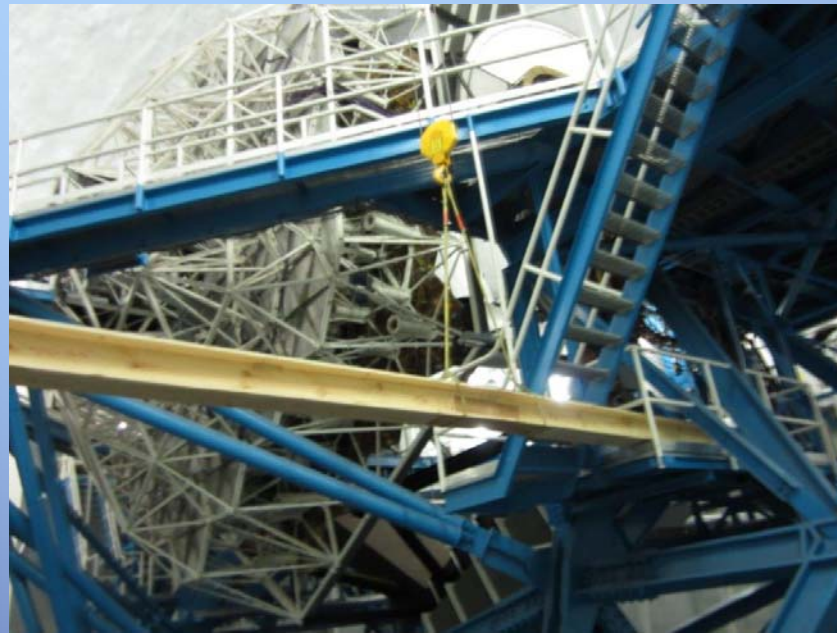


Platform Layout

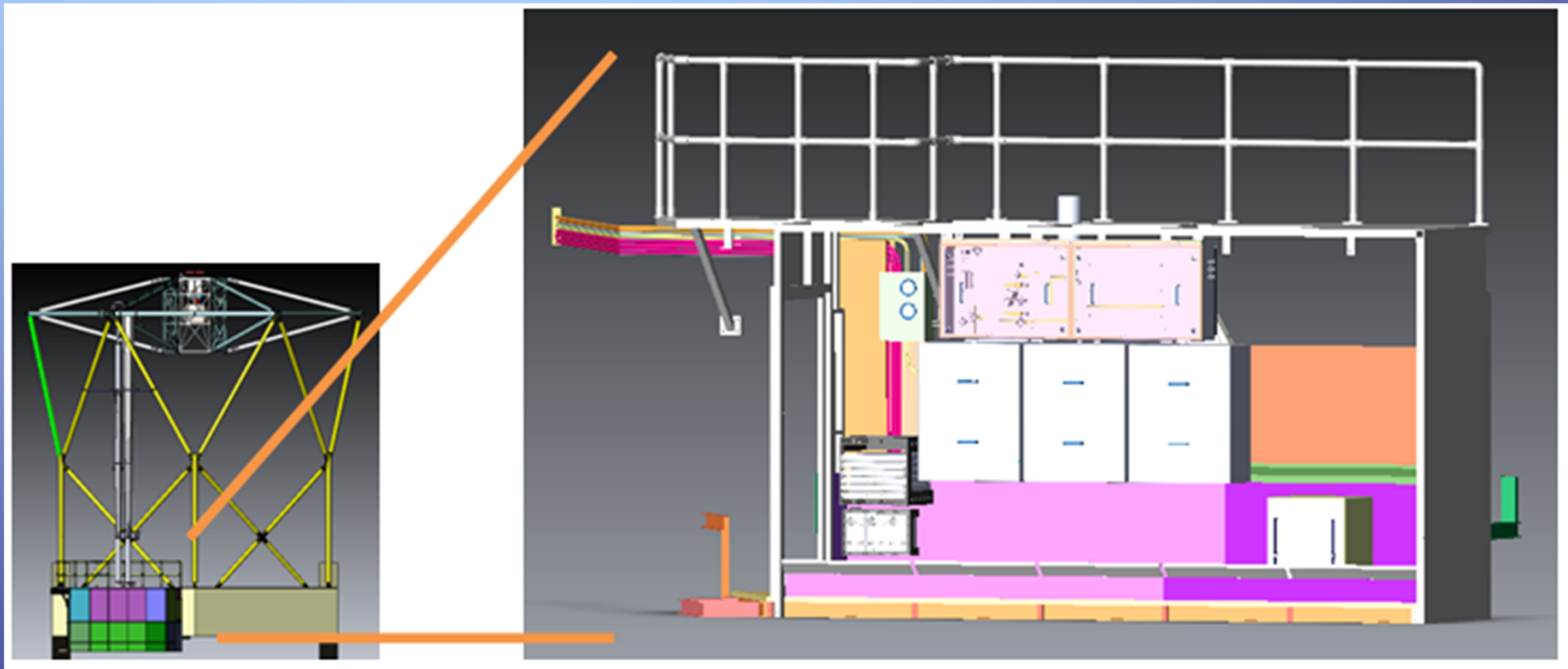


Platform next steps

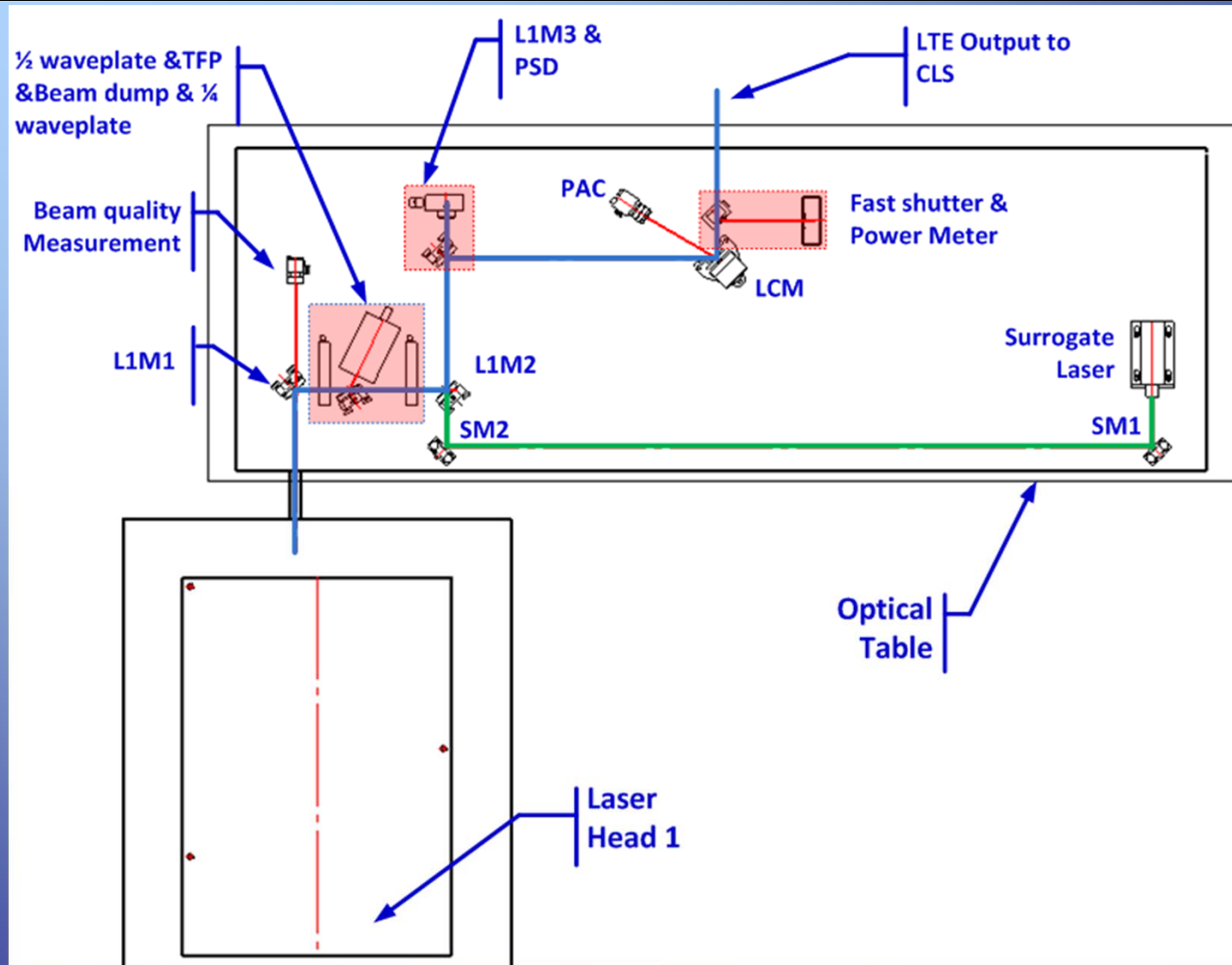
- Platform current being fabricated; completion in Jan 2015
- Installation Jan-Mar 2015
- I&T challenge; to install platform without any observing down time



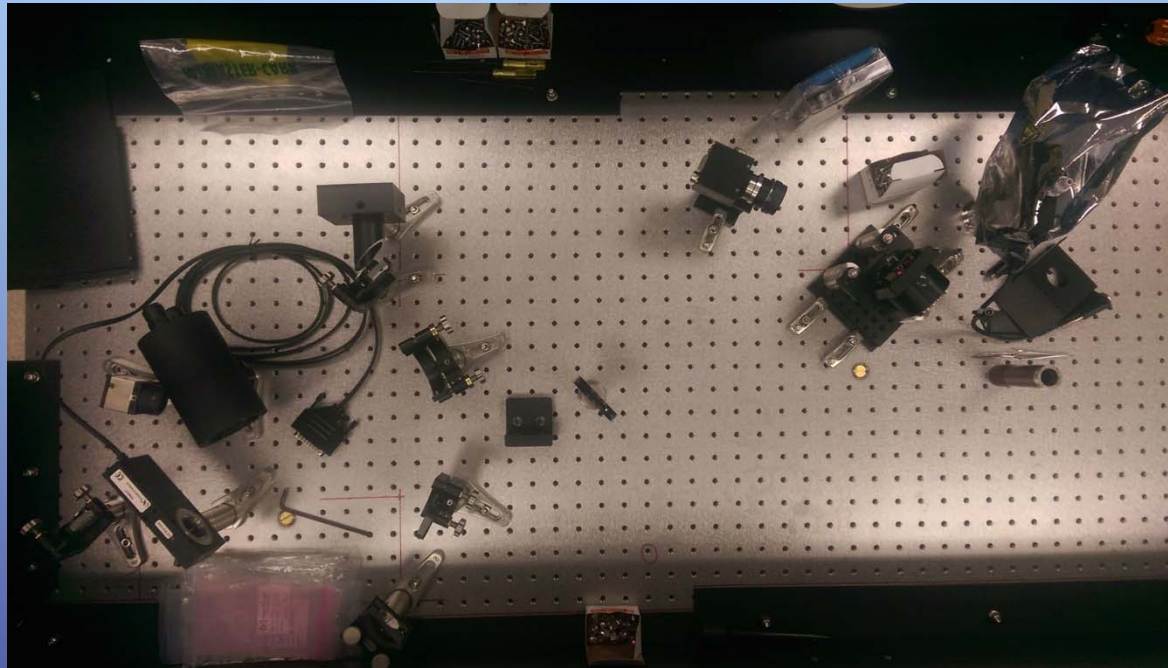
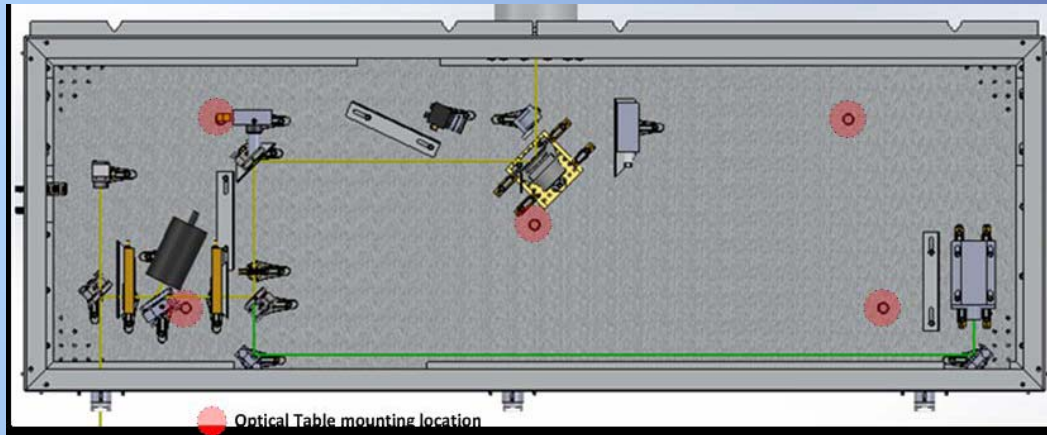
Laser Room on Elevation Ring



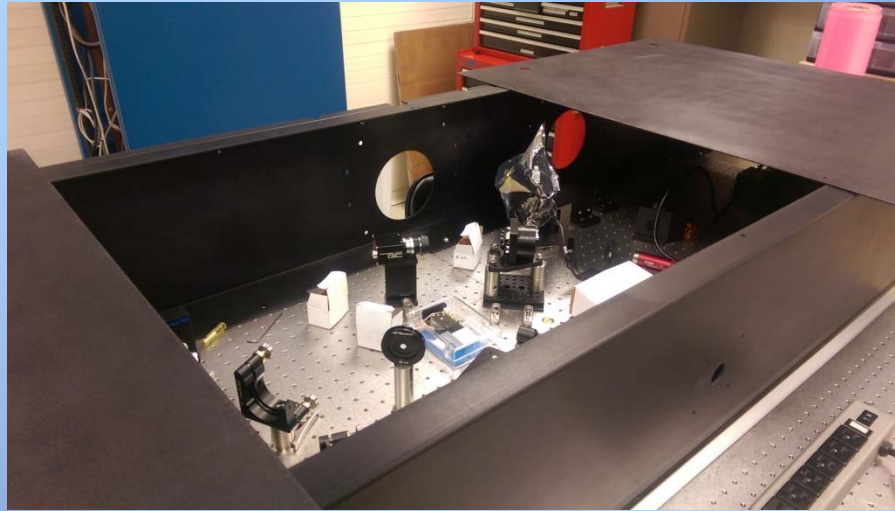
LTE Layout for NGL



LTE Optical Bench



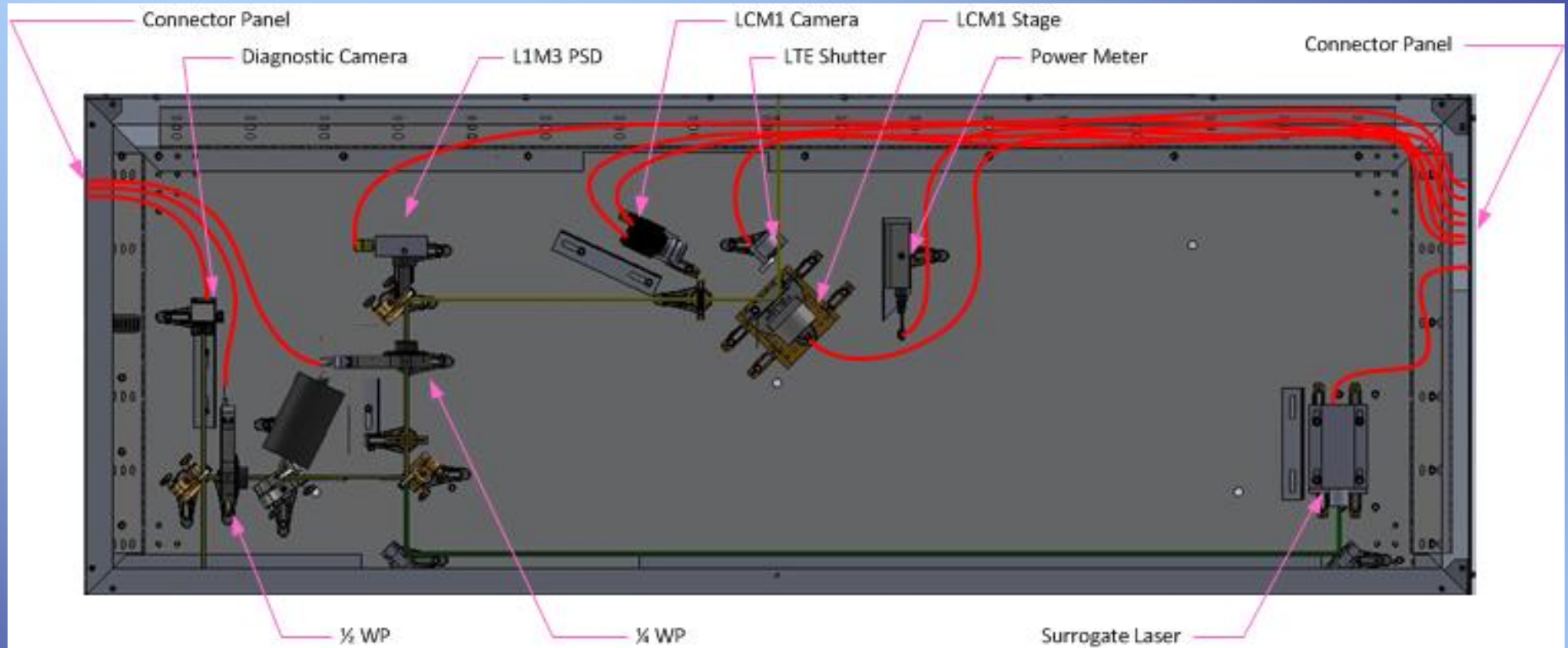
LTE Optical Bench Enclosure



HQ LTE Testing

- Align LTE with TOPTICA laser
- Integrate LTE components with electronics and safety system
- Verify all LTE functionality
- Use LTE components to verify laser performance (WFS, power heads, PSD)
- Integrate LTE with mounting frame
- Characterize LTE performance

LTE Devices/Cabling



LTE Devices

- Shack-Hartmann Diagnostic Camera (Thorlabs WFS 150)
- WP1 and WP2 (control power and polarization)
 - Newport PR50CC
- Position Sensing Diodes
 - On-Trak OT-301
 - Position and power
- LCM1
 - OIM-101 voice coil stage
 - Account for telescope flexure and vibration
 - Stage driven $\frac{1}{4}$ span \rightarrow 0.2 urad/bit or 4.8um/bit 12 meters away



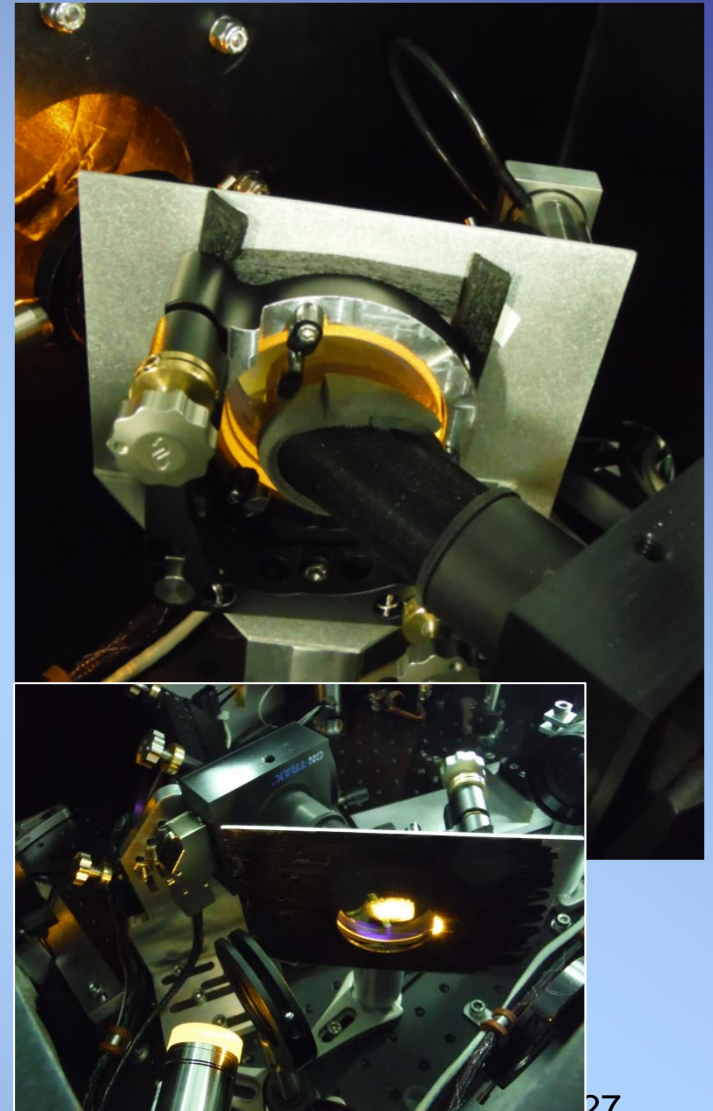
LTE Devices

- LCM1 Camera
 - AVT GC-1290
 - GigE interface, SW configurable gain/exposure
 - 48px/mm plate scale; ~150 illuminated px w/ 3mm laser beam
- LTE shutter
 - Custom built EOPC shutter with position feedback
- Power Measurement
 - Coherent PowerMax series thermopile
 - Liquid cooled with remote measurement
- Surrogate green laser
 - Lasermate compact laser modules (adjustable power)



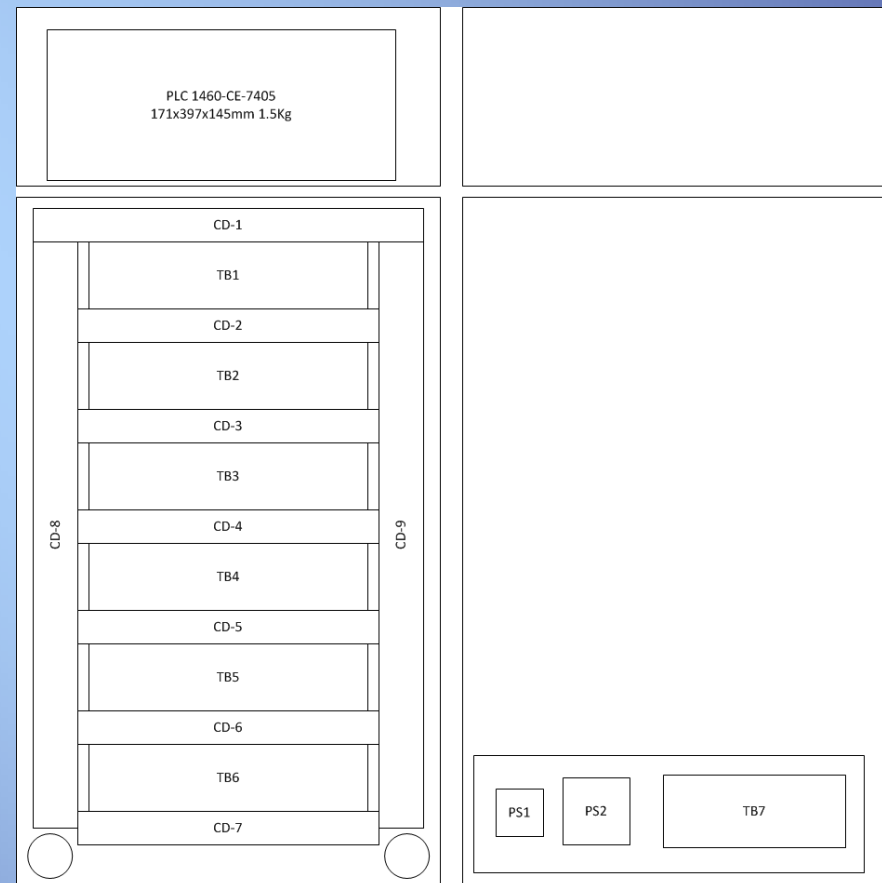
Challenges

- PSD stray light
 - Working with leakage signal through highly reflective optic
 - Implement Shrouds and blacked areas of uncoated optic
 - Leakage dependent on polarization (10x change S vs P)
 - 532nm (surrogate) leakage quite different than 589nm



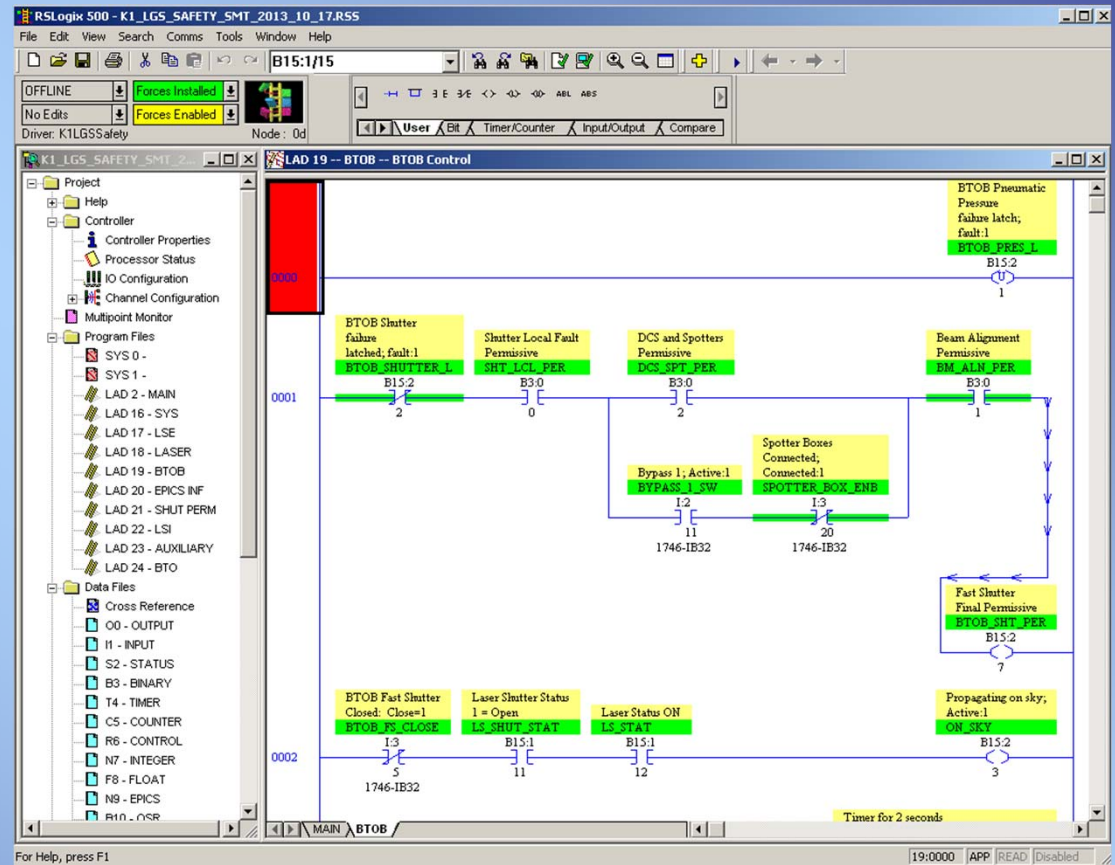
Safety System Controller

- Allen Bradley SLC500 series PLC
- Used on the Keck I Safety System



PLC Programming

- RSLogix 500 Programming Environment
- Similar to Keck I for launch system
- Main differences are laser related



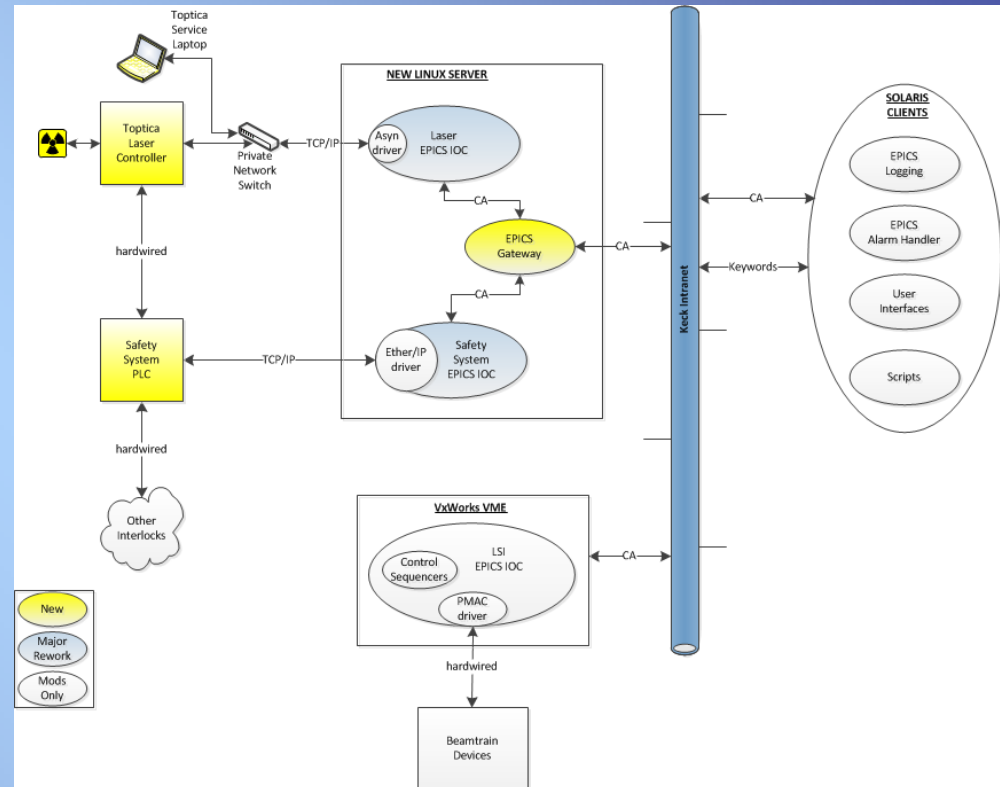
Safety System Indicators and Key Switches

- Existing indicator panels
- Keyswitch panels to tag out system as well as for maintenance
 - Disable shutters
 - In dome propagation

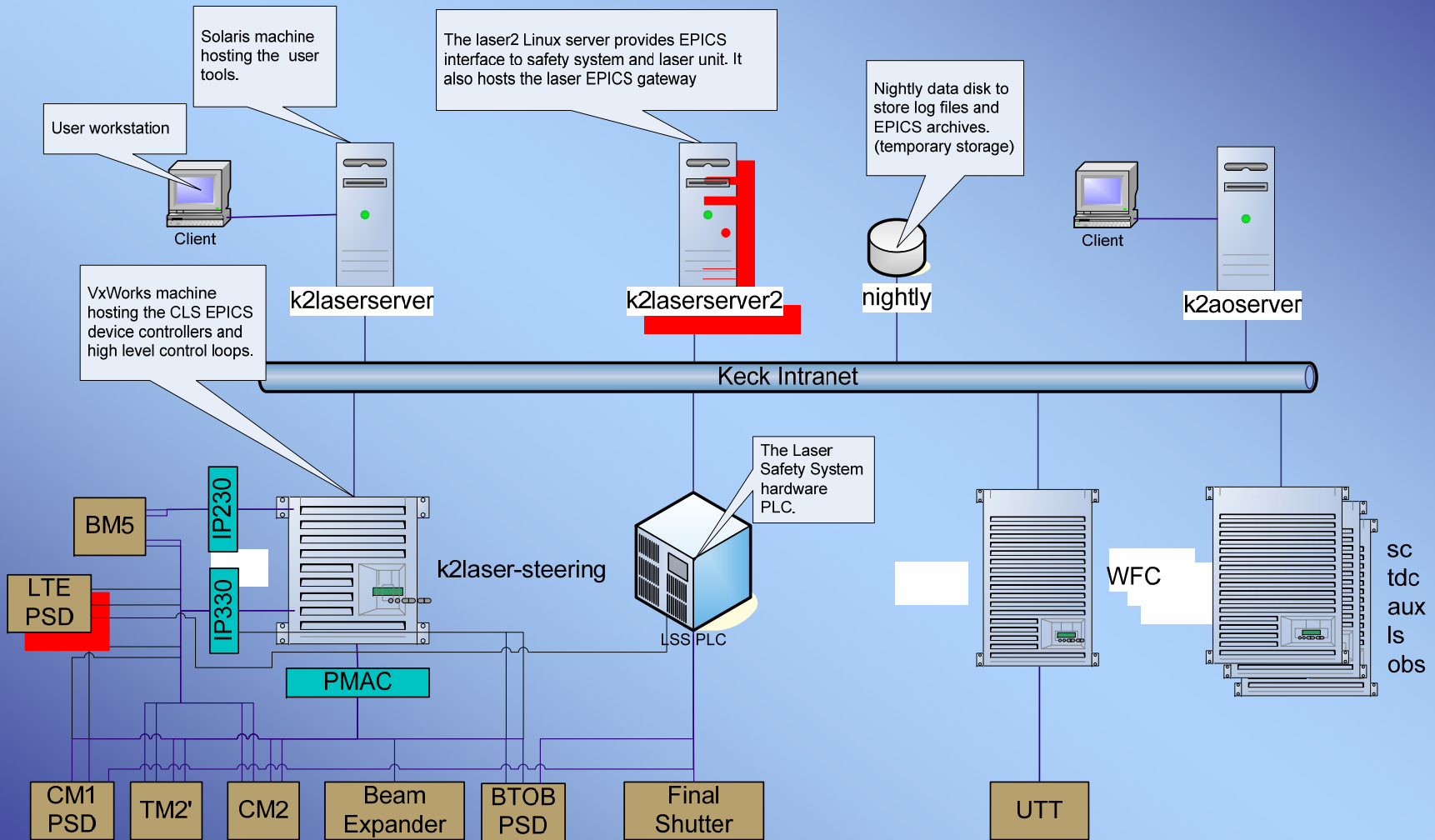


Software Architecture

- EPICS based;
Experimental Physics
Industrial Control System
- Laser Controller (Linux
Server)
- Laser Safety System (Linux
IOC via server)
- Laser Steering Interface for
motion control (PMAC with
VxWorks)



Control System Network



User Interfaces Updates

Insertion of 1/4 waveplate

K2 CLS Sequencer

File GUIs Scripts Terms 15:13:44 HST

Sequencer State: STBY

Uninitialized

PMAC laser2 (LSS) EZAR

INITIALIZE SHUTTER

ALIGN IDLE

PROPAGATE HALT ALL

15:13:32 - TM2 flexure correction loop open.
 15:13:32 - ***WARNING: UTT CLMP loop is open.
 15:13:32 - BM5 coordinated motion loop open.
 15:13:32 - BTOB Focus tracking loop open.
 15:13:42 - WARNING: One or more CLS EZAR archives not running.

- Wavelength Shift Failed
- Wavelength Shift OOR
- Center Wavelength OOR
- Low/high Coolant Temp
- Wavelength Return Fail
- Laser Timing
- Waveguide Temp
- System Temp

SEARCH

BAD OK NONE

General Faults

Modes

Interlocks

Wavelength Stat

YES NO Lock Zero Cross

Laser ON

EXIT

And more...

/kroot/rel/ao/ls1/defa

EPICS IF

Switches/Bypass

Temps/Analog

OA Menu

Pointing CTRL

E-STOP

Reset

Start Pointing

EXIT

IsOaMenu.dl

OA Permissive

deny grant

Permissives

| | Current | Latched |
|--------------------|--------------------------|--------------------------|
| DR: | <input type="checkbox"/> | <input type="checkbox"/> |
| LTCS: | <input type="checkbox"/> | <input type="checkbox"/> |
| East (K2) Spotter: | <input type="checkbox"/> | <input type="checkbox"/> |
| West (K1) Spotter: | <input type="checkbox"/> | <input type="checkbox"/> |
| DCS: | <input type="checkbox"/> | <input type="checkbox"/> |
| TBAD Health: | <input type="checkbox"/> | <input type="checkbox"/> |
| TBAD detection: | <input type="checkbox"/> | <input type="checkbox"/> |
| Spotter Packs: | <input type="checkbox"/> | <input type="checkbox"/> |
| Satellites Perm: | <input type="checkbox"/> | <input type="checkbox"/> |
| BTO Track: | <input type="checkbox"/> | <input type="checkbox"/> |

Key Switches: grant

Final Permissive:

RESET

Final Shutter: notOpen

Fast Shutter: notOpen

Satellite Window: closed

Final Shtr Cmd: OPEN CLOSE

EXIT LASER E-STOP

Over-Ride Panel

| | | |
|------------------------|--------------------|---------|
| DCS Permissiv Control | deny grant | deny |
| LTCS Permissiv Control | deny grant | deny |
| Sats Permissiv Control | deny grant | deny |
| TBAD Bypass Control | notbypassed bypass | notBypa |

./lsCommands.dl

Laser ON Laser Control

Sequencer Status This is the sequencer

Laser State REV EPIC

shut.down Startup ERROR

string

Shutter REV

Close Open ERROR

string

Calibrate / L REV

CALIBRATE ERROR

string

Low Power Mode Wavelength Controls Shift Tune

OFF OFF UP DN

Wavelength Status

| YES | NO | Lock | Zero Cross |
|--------------------------|--------------------------|--------------------------|--------------------------|
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Phase Relation Ctrl

UP phase up error

DN phase down error

./lsFaults.dl

OK NOT Faults

| | | |
|--------------------------|--------------------------|-----------------------|
| <input type="checkbox"/> | <input type="checkbox"/> | Door Open |
| <input type="checkbox"/> | <input type="checkbox"/> | Laser Key Off |
| <input type="checkbox"/> | <input type="checkbox"/> | LIB Interface |
| <input type="checkbox"/> | <input type="checkbox"/> | Coolant Flow MORE |
| <input type="checkbox"/> | <input type="checkbox"/> | PXI Heartbeat |
| <input type="checkbox"/> | <input type="checkbox"/> | Shutter Open Failure |
| <input type="checkbox"/> | <input type="checkbox"/> | Shutter Close Failure |
| <input type="checkbox"/> | <input type="checkbox"/> | System Temperature |
| <input type="checkbox"/> | <input type="checkbox"/> | Zero Diode Current |
| <input type="checkbox"/> | <input type="checkbox"/> | Current Control |
| <input type="checkbox"/> | <input type="checkbox"/> | Condensation |
| <input type="checkbox"/> | <input type="checkbox"/> | SFG Temp OOR |
| <input type="checkbox"/> | <input type="checkbox"/> | Diode Temp OOR |
| <input type="checkbox"/> | <input type="checkbox"/> | Waveguide Temp OOR |
| <input type="checkbox"/> | <input type="checkbox"/> | High Coolant Temp |
| <input type="checkbox"/> | <input type="checkbox"/> | LCS Error |

EXIT

Startup/Shutdown Procedure

- Pre-req: LEI IOC on, LSS IOC on, EPICS gateway on, LSI-Crate on, Power on. **In case it is not on, run the red lines**
 - From k2laserserver2 (Linux IOC)
 1. Start LEI IOC (2 sec)
 2. Start LSS IOC (2 sec)
 3. Start EPICS gateway (2 sec)
 4. Start LEI GUI (2 sec)
 5. Go to OBS mode with the following sequence (99 sec , source KAON 1051)
 1. STANDBY -> READY (6 sec)
 2. READY -> ON (85 sec)
 3. ON -> (OBS 8sec)
 - From k2laserserver or k2laserver2
 1. Boot LSI crate (240 sec)
 2. Power On CLS device (~30 sec, see CLS TWIKI page)
 3. Start k2clsSequencer.py GUI (5 sec)
 4. From menu, run Start Of Night script (10 sec)
 5. Push INITIALIZE button (worth case, after a reboot of the crate: 180 sec, normal operation, less than 60 sec)
- Shutdown:
 1. GO to STANDBY with LEI GUI (70 sec , source KAON 1051)
 1. OBS -> ON (4 sec)
 2. ON -> READY (62 sec)
 3. READY -> STBY (4 sec)
 2. From k2clsSequencer.py menu, run End Of Night script (10 sec)

176 sec < STARTUP TIME < 572 sec

SHUTDOWN TIME = 80 sec



Telemetry

- (EPICS logging) ezar files
 - IsPointingDiag.ezar, IsTemps.ezar, IsFlexDiag.ezar, laserDiag.ezar will be updated by adding new TOPTICA channels and removing obsolete old laser channels
- TOPTICA independent data logging by laser
- TOPTICA independent data logging by service software laptop

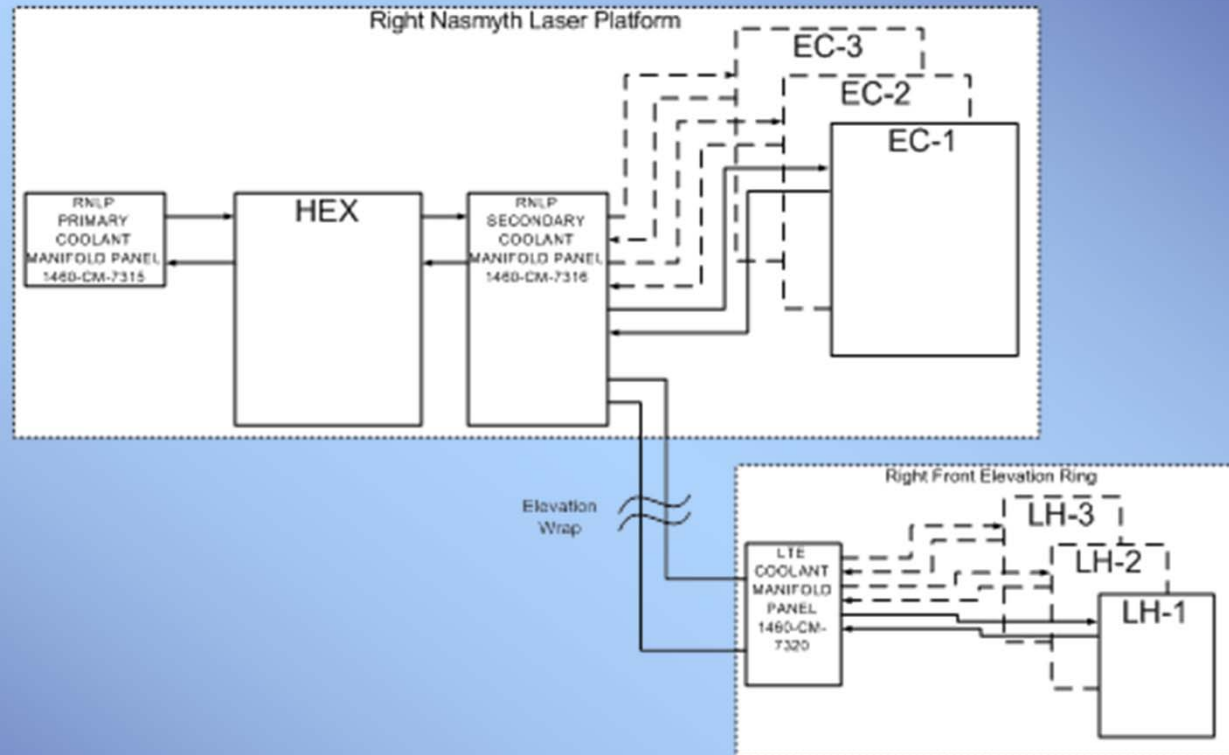
Laser Power Requirements

| # | Location | Clean Power Usage (W) | | Commercial Power Usage (W) | |
|---|------------------------------|-----------------------|-------------|----------------------------|-------------|
| | | Single Laser | Three Laser | Single Laser | Three Laser |
| 1 | Laser Table | 50 | 50 | 100 | 100 |
| 2 | Right Nasmyth Laser Platform | 1400 | 4200 | 2500 | 2500 |
| 3 | AO Electronics Vault | 300 | 300 | 0 | 0 |
| | Net Total | 1750 | 4550 | 2600 | 2600 |

- Scaled up to account for aging of diodes
- Laser system feeds limited to 10A breakers for laser safety
- Compared to existing K2 dye laser system (55kW)



Cooling System Requirements



- Primary loop operating near 0°C
- Secondary loop operating at 15°C
 - Lines must be insulated to prevent heat from going into the dome



LGS AO Road Map

- Current Systems
 - CLS commissioning

| KECK 1 | KECK 2 |
|----------------------|----------------------|
| LCMT Laser | LLNL Dye Laser |
| Free Space Transport | Center Launch System |
| OSIRIS Spectrograph | NIRC2 Imager |



LGS AO Road Map

- 2015 and beyond

| K1/2 | Project | Completion |
|-------------|------------------------------|-------------------|
| 1 | NIR Tip-Tilt Sensor | 2015 |
| 1/2 | On-axis PSF-R Demo | 2015 |
| 1/2 | Off-axis PSF-R Demo | 2015 |
| 1 | OSIRIS IFS Upgrade | 2015 |
| 1 | Enhanced NIR Tip-Tilt Sensor | 2015 |
| 2 | TOPTICA Laser | 2016 |
| 1 | OSIRIS Imager Upgrade | 2016 |

Mahalo

