Lunar Laser OCTL Terminal (LLOT)

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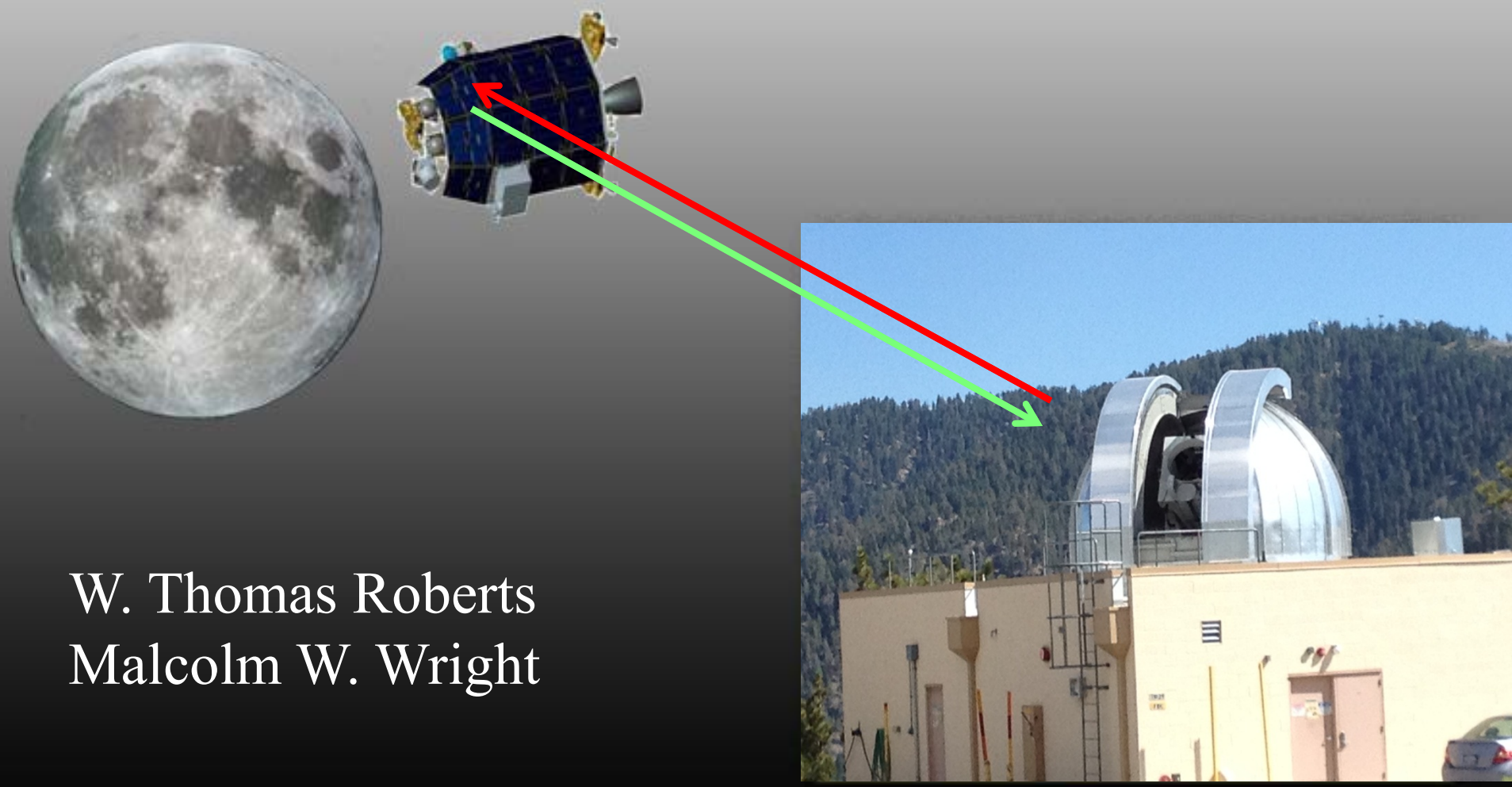
California Institute of Technology

Optical Systems



W. Thomas Roberts
Malcolm W. Wright

Laser Description

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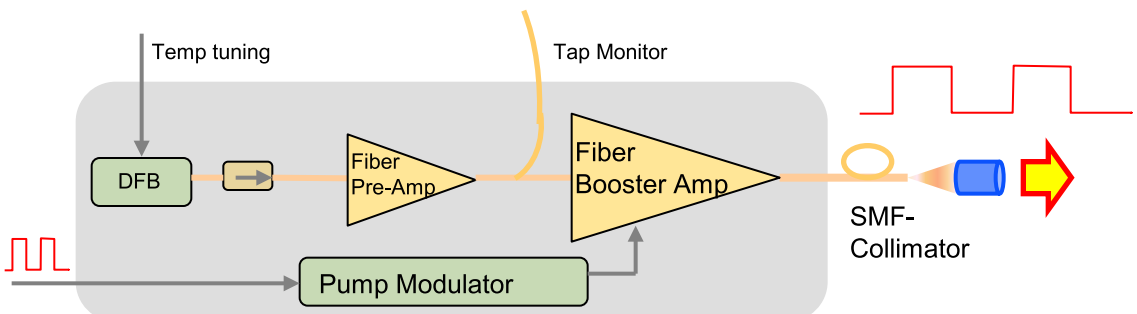
Requirement	Value	Comment
Average power, W	10	Link Budget requires 60 W ⇒ 6 devices
PRF, kHz	1	Flight system acquisition
Pulse-width, μs	500	50 % duty cycle
Peak Power, W	20	
Center Wavelength, nm	1567.95	+/- 0.1 nm - dλ/dT = 0.1 nm/deg C, 0.1 deg C incr.
Wavelength separation, MHz	> 10	Eliminate coherence effect with multiple lasers
Line-width, nm	< 0.05	~10 MHz DFB for receive filter band-pass
Polarization	Unpolarized	
Extinction Ratio, dB	13	Directly modulated pump lasers
Beam Quality	SM	M^2 < 1.3



Custom development to obtain narrow line-width at high power

Laser Test Results – Pulsed Power and Beam

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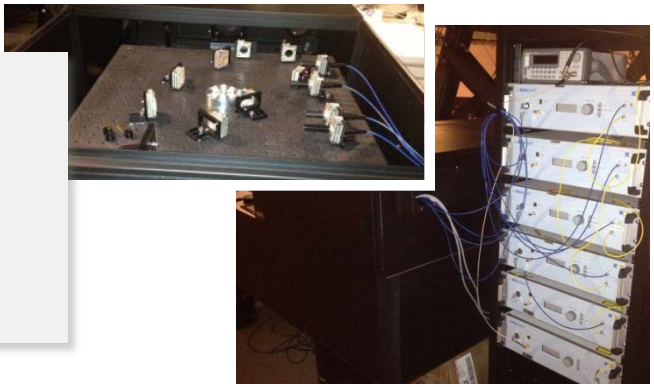
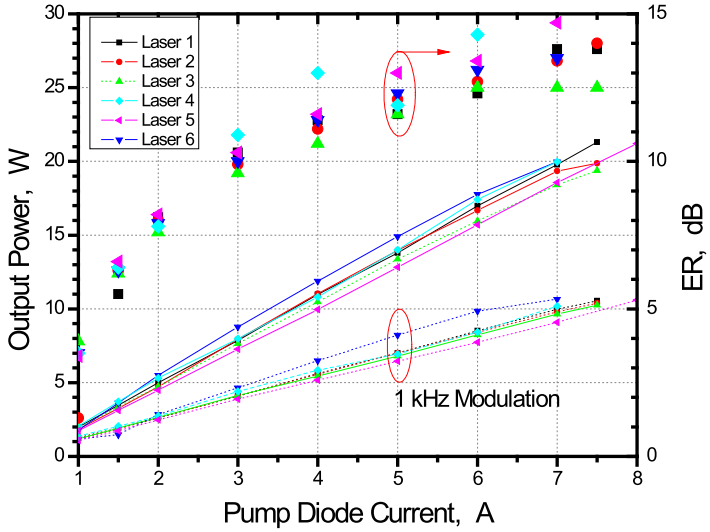
- 20 W cw power and P_{avg} > 10 W with 1 kHz mod. each
- ER 13 dB at high power
- $M^2 \sim 1.09$

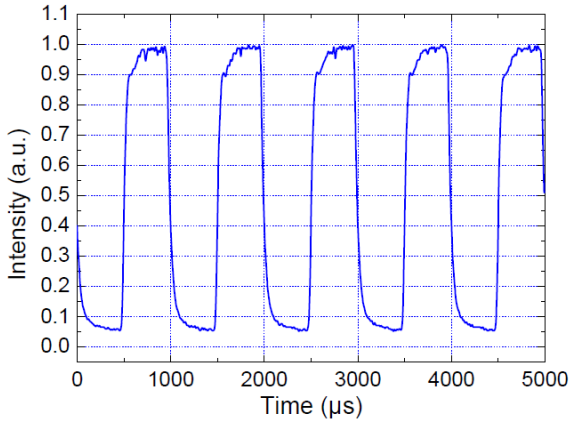
Rack mounted laser

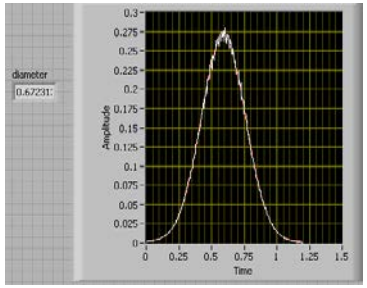


Output Power & ER

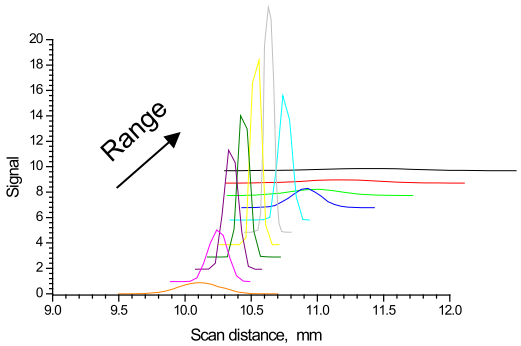


Example Time Trace





Gaussian beam fit



Beam profile measurement

60 W average beacon power from SMF

Laser Test Results –Spectral Measurements

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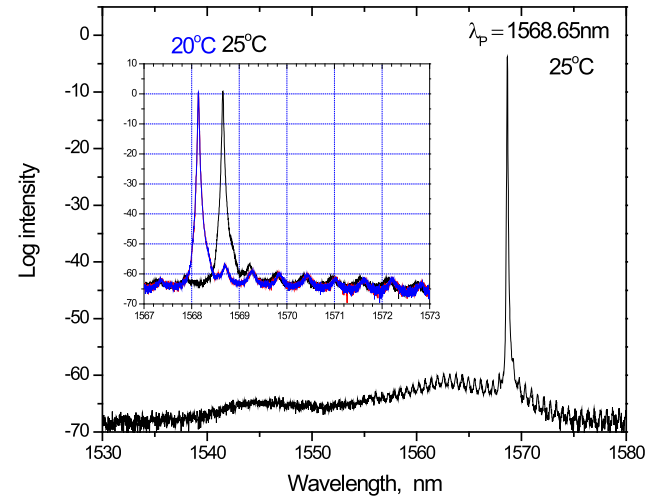
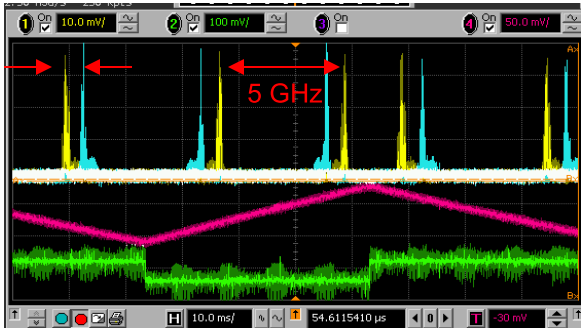
- λ_p = 1567.95 ± 0.005 nm
  - Absolute measurement on OSA and OCPM, rel. measurement on fiber FP Interferometer (10 MHz BW)
  - Temp tuned center wavelength (- dλ/dT = 0.1 nm/°C) to obtain Δλ > 10 MHz, 0.1 ° C temp control required
- Line-width < 100 MHz (1 pm), instrument limited
- OSNR > 55 dB, > 99 % energy in +/- 0.1 nm

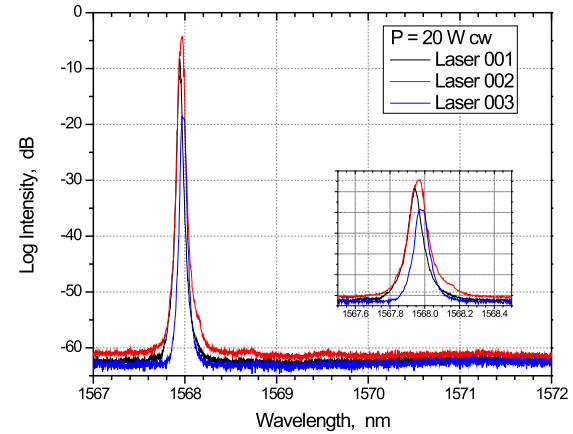
Wavelength Spectra



Fabry Perot Spectrum

Drift in relative wavelength over 15 min (~ 0.7GHz)





Center wavelength tunable to match receive filter

LLOT Optics Description Overview

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2 separate subsystems

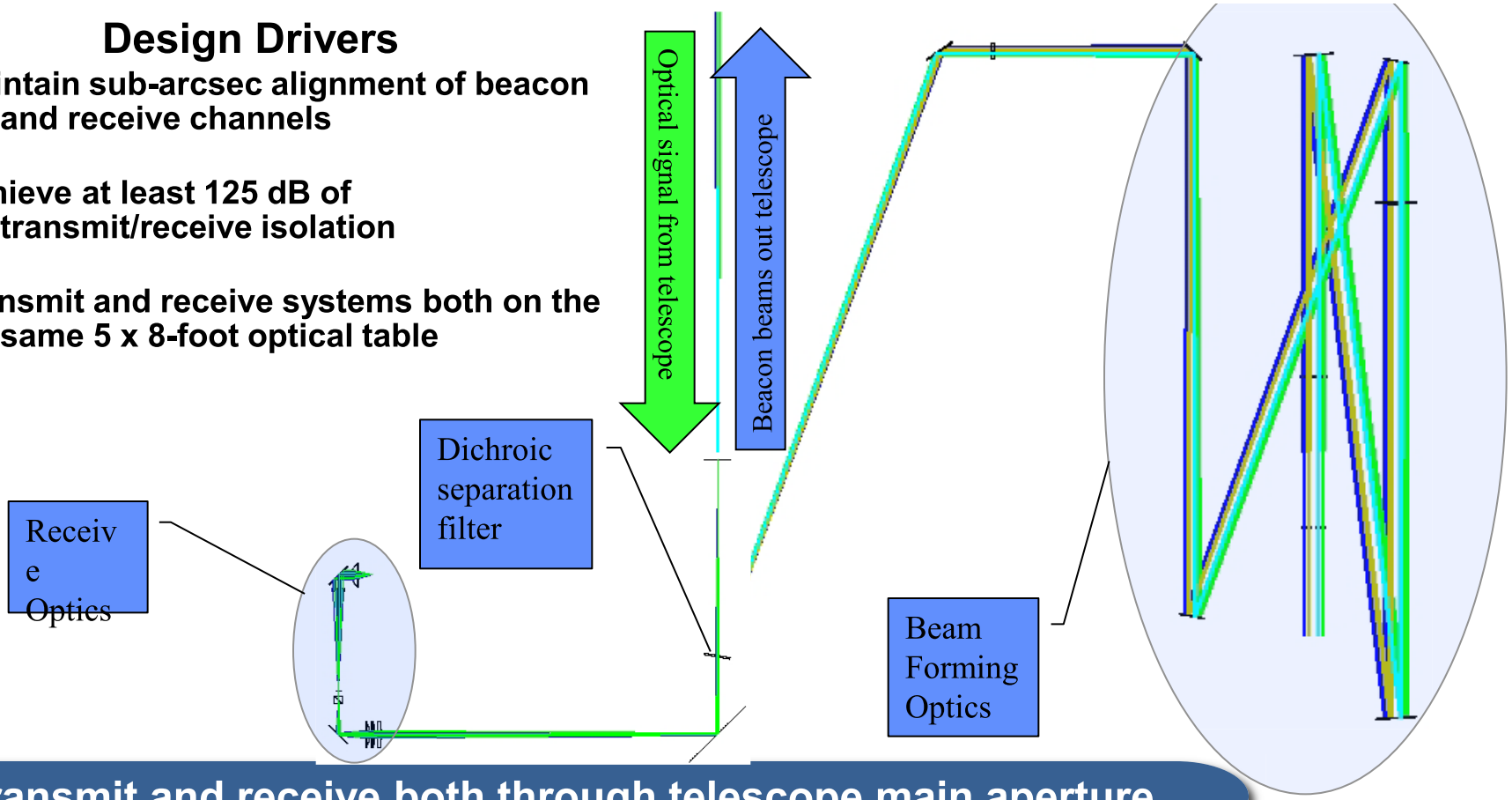
- **Transmit system controls alignment and divergence of 6 beams**
- **Receive system sends light to acquisition camera and data detector(s)**

Design Drivers

Maintain sub-arcsec alignment of beacon and receive channels

Achieve at least 125 dB of transmit/receive isolation

Transmit and receive systems both on the same 5 x 8-foot optical table



Transmit and receive both through telescope main aperture

TRANSMIT SYSTEM DESIGN DRIVERS

Divergence

- **110 urad (FW $1/e^2$) during acquisition**
- **40 urad (FW $1/e^2$) during comm**
- **Beams may not focus outside of telescope**

Continuously monitor beam divergence and power

Throughput losses less than 3.5 dB including telescope losses

BEAM-SHAPING SYSTEM

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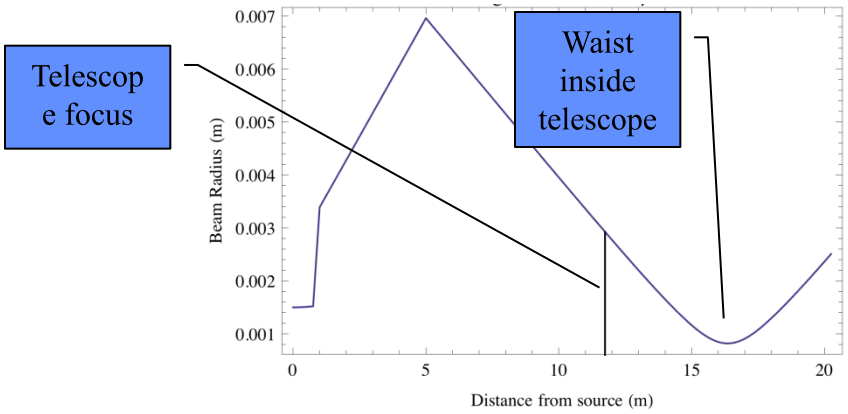
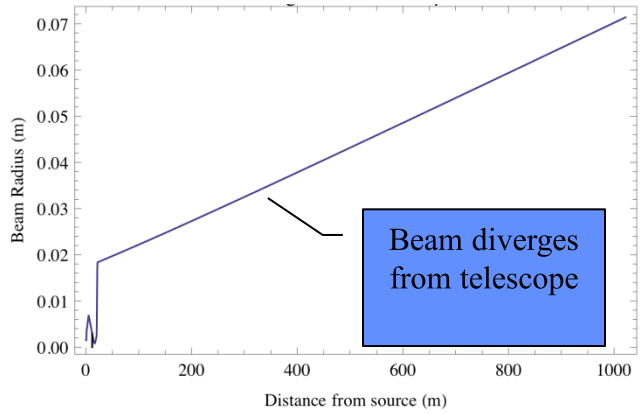
Divergence Requirement: 110 μrad during acquisition and 40 μrad during comm

- Six parallel co-propagating beams on lower table
  - Zoom system adjusts divergence of beams individually
  - Propagation along table allows beams to diverge to appropriate size
- Parallel beams enter converger lens
  - Converger placed one focal length from telescope focus
    - Parallel beams always converge at telescope focus
    - Beam size at focus determines divergence on sky
  - Beam size and divergence entering converger adjusts beam waist location
    - Waists must be between telescope focus and primary

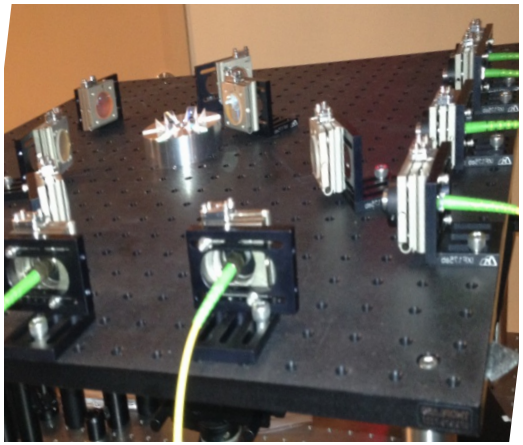


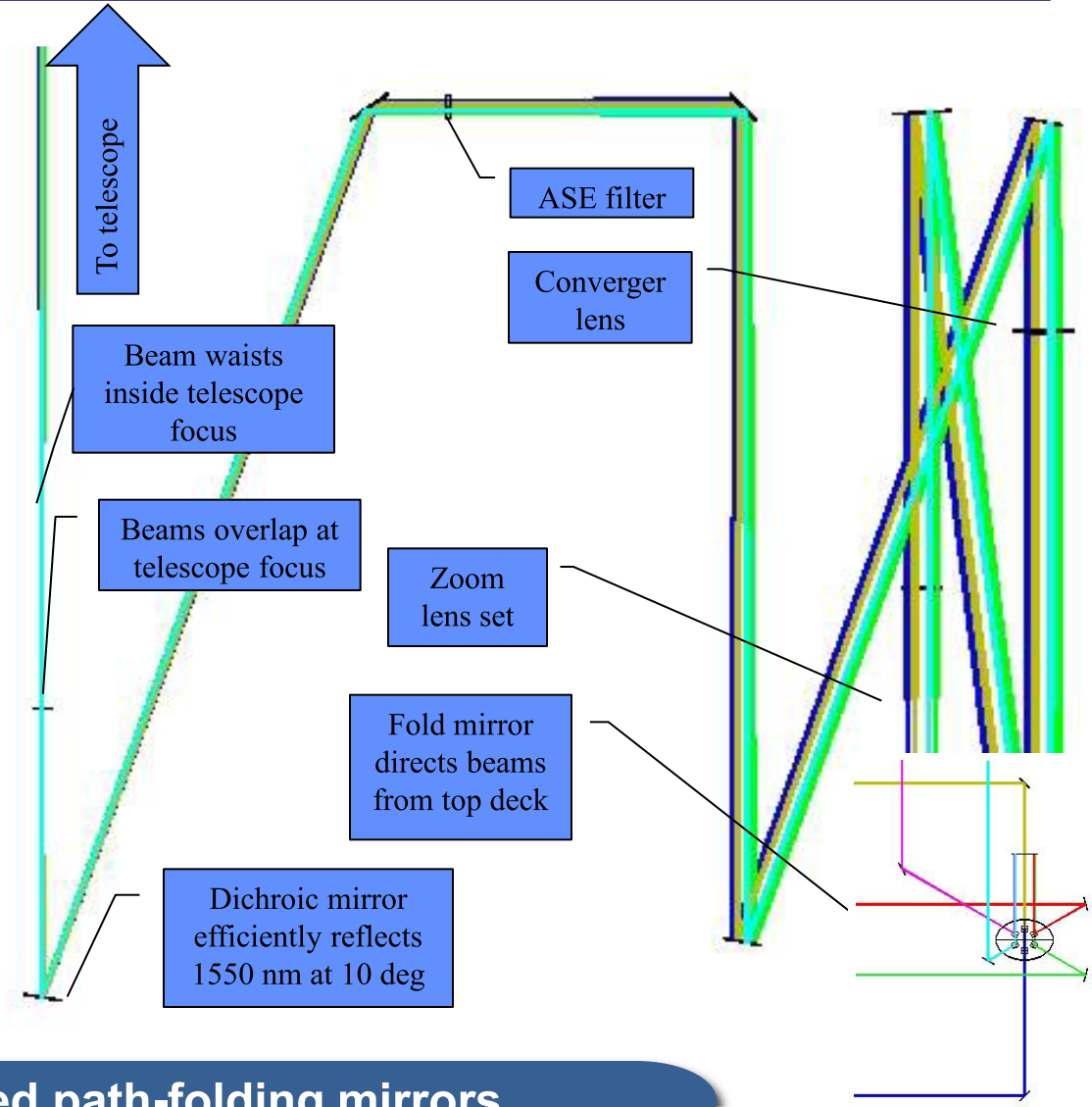


Spot sizes (divergences) change – positions (alignment) fixed

TRANSMIT SYSTEM DESCRIPTION

- **Top-deck allows convenient adjustment of beam alignment**
- **Long paths required to match telescope F/#**
- **Zoom lens system and rail-mounted converger lens aligned with table**





Transmit design reduces required path-folding mirrors

ZOOM SPOTS IN PUPIL

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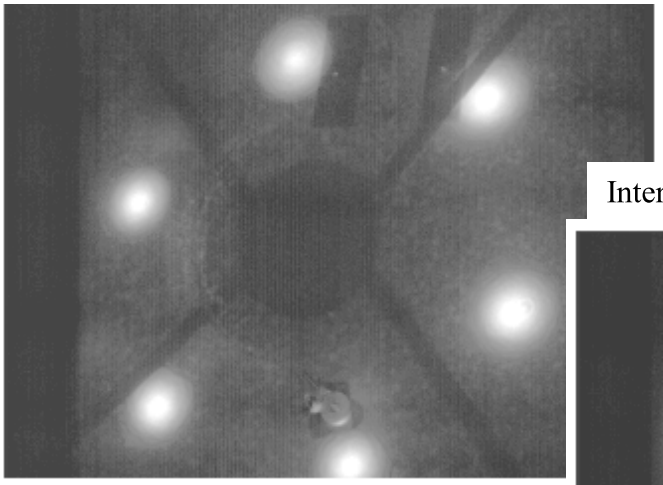
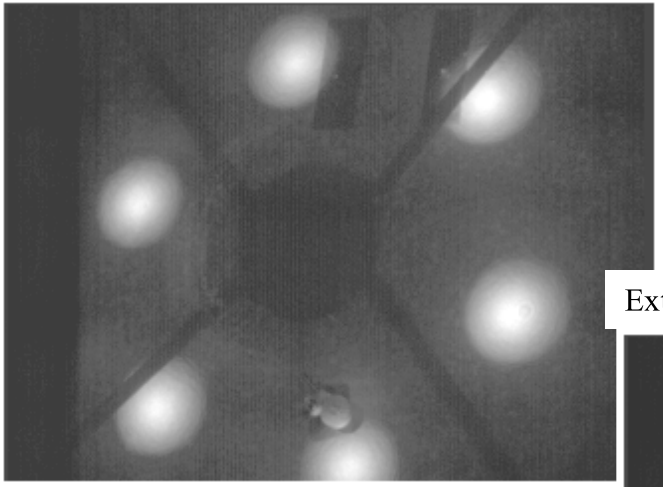
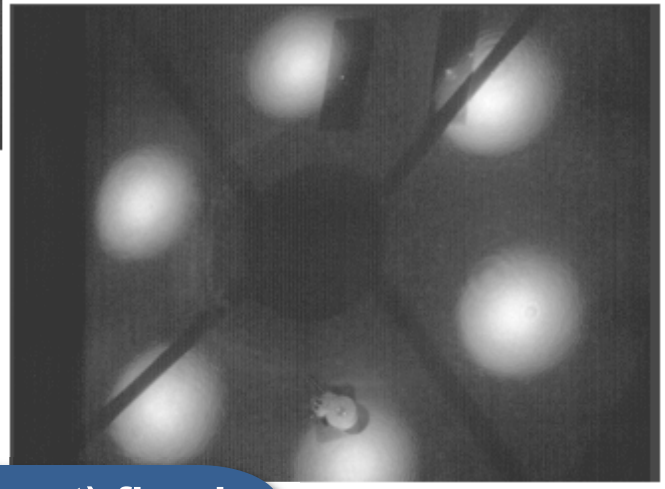
Extremity 1 (110 μrad) of zoom spots OCTL dome



Intermediate zoom spot location OCTL dome

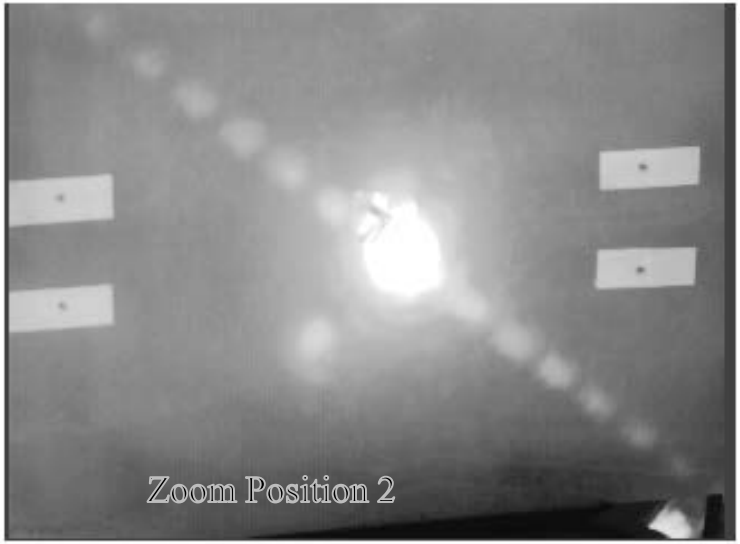


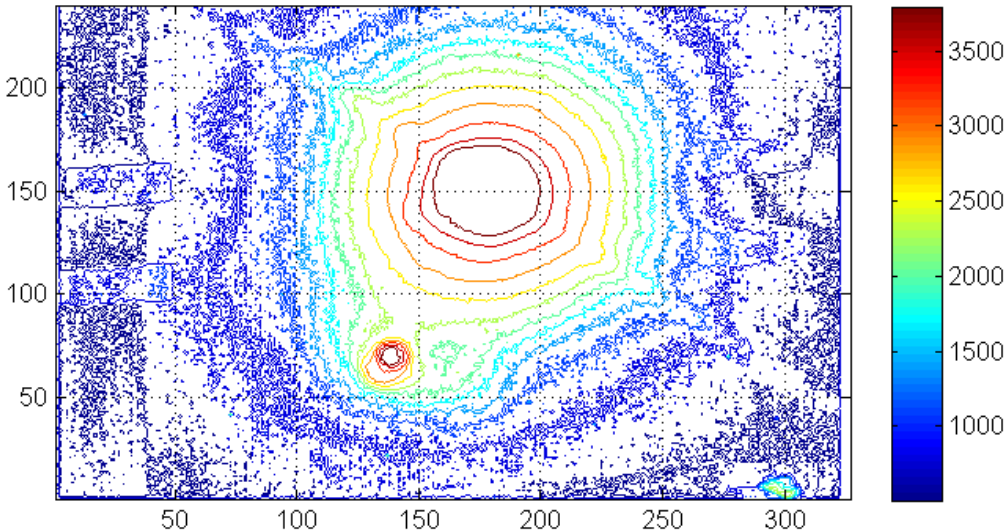
Extremity 2 (40 μrad) of zoom spots OCTL dome



Spot sizes (divergences) change – positions (alignment) fixed

ZOOM SPOTS FOCUSED AT 1.65 KM

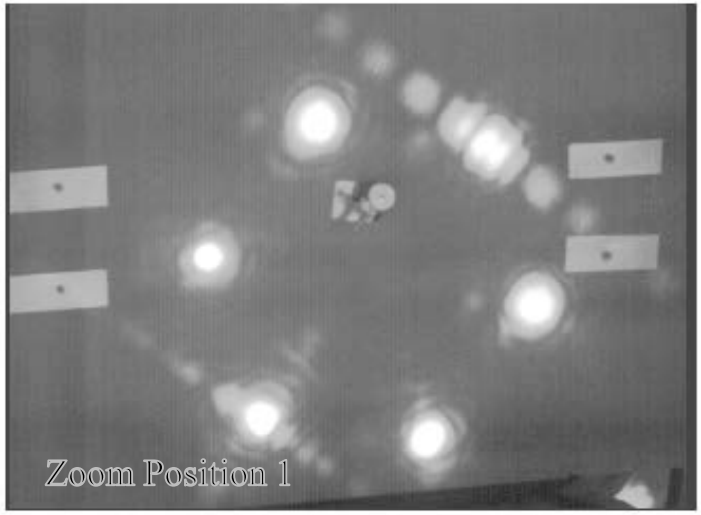


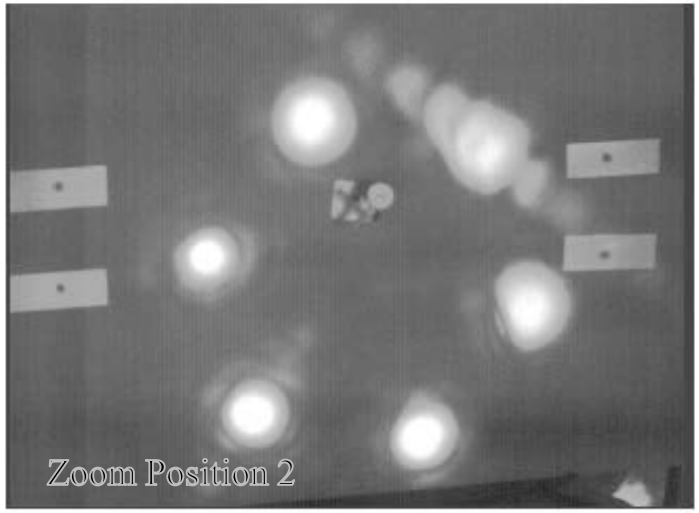


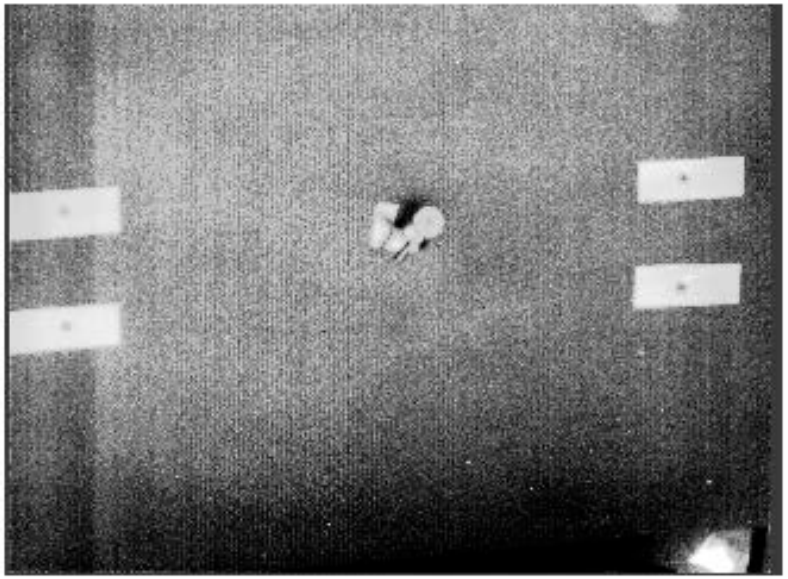
Circular beam contours show excellent far-field beam quality

Insignificant spot motion – alignment maintained – good spot

ZOOM SPOTS FOCUSED AT INFINITY







Target board background with no laser

Insignificant spot motion – alignment maintained

TRANSMIT BEAM MONITORING

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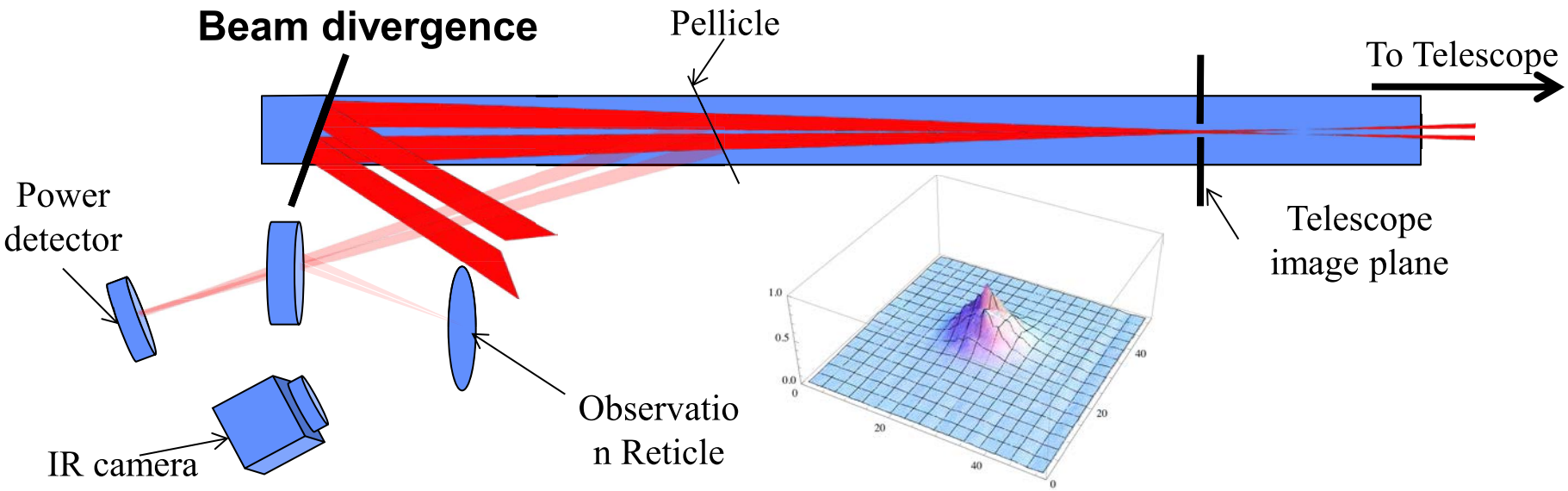
- Angle-tune pellicle to generate < 1% insertion loss (~15 deg AOI)
- Power Monitoring
  - Beams focused onto IR detector
  - Detector power calibrated against transmit power
- Beam Monitoring
  - Image of beam set on camera provides real-time evaluation of
    - Beam alignment
    - Beam divergence



Continuous monitoring of power, alignment and beam shape

RECEIVE SYSTEM DESIGN DRIVERS

Throughput losses less than 8.0 dB including telescope

Efficiently reject beacon light

- **120 W peak power at 1568 nm**
- **~ 1 W peak power ASE around 1550 nm**

Effect seamless transition between acquisition and comm channels

Efficiently couple comm signal to 62.5 um, 0.275 NA low-dispersion fiber

Banner for crisp “so what?” summary

RECEIVE SYSTEM DESCRIPTION

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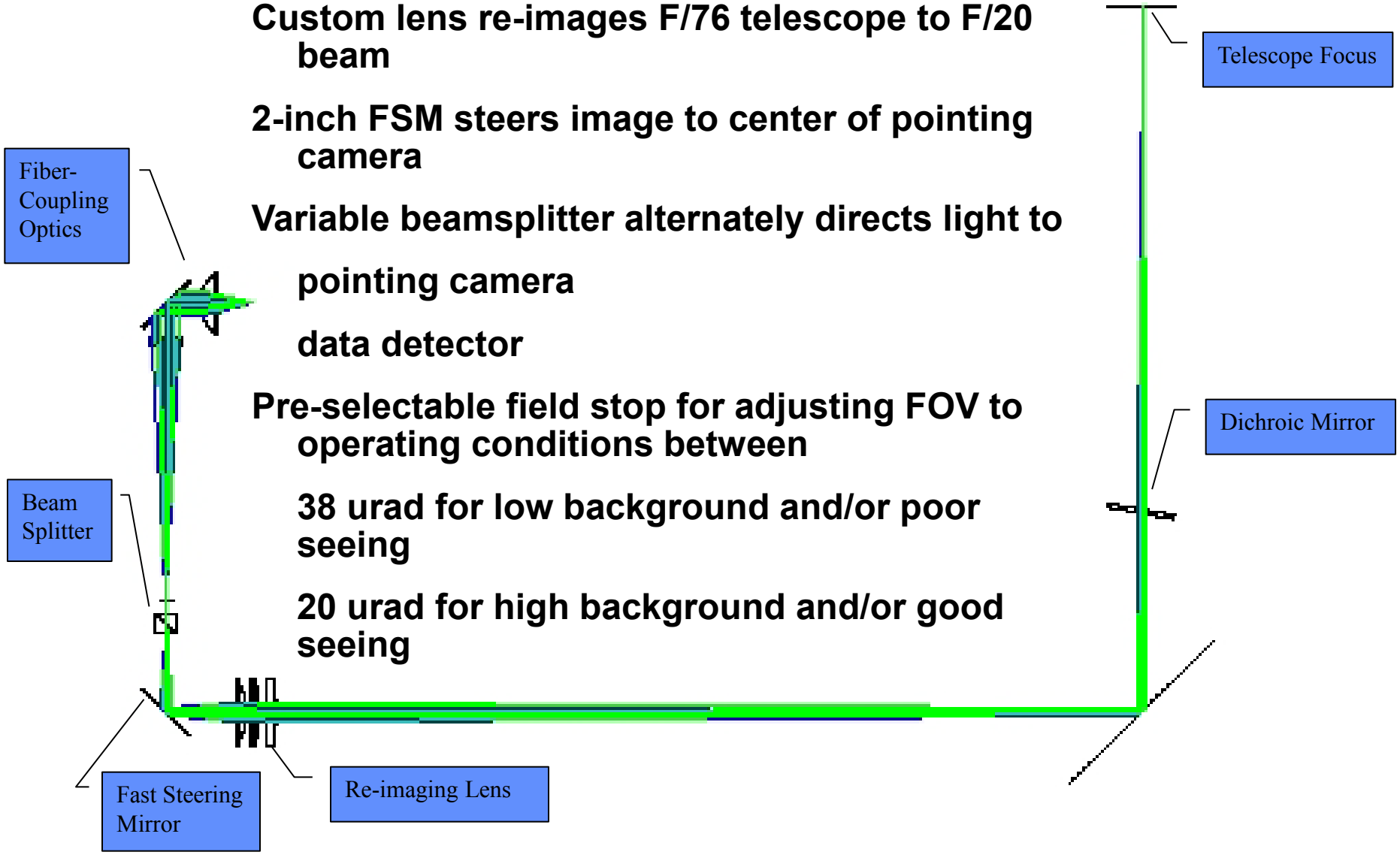
- Custom lens re-images F/76 telescope to F/20 beam
- 2-inch FSM steers image to center of pointing camera
- Variable beamsplitter alternately directs light to
  - pointing camera
  - data detector
- Pre-selectable field stop for adjusting FOV to operating conditions between
  - 38 urad for low background and/or poor seeing
  - 20 urad for high background and/or good seeing



WSi DETECTOR CHANNEL

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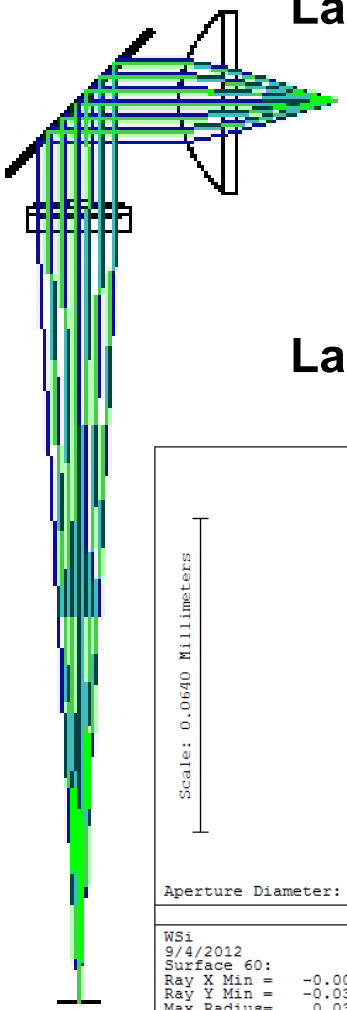
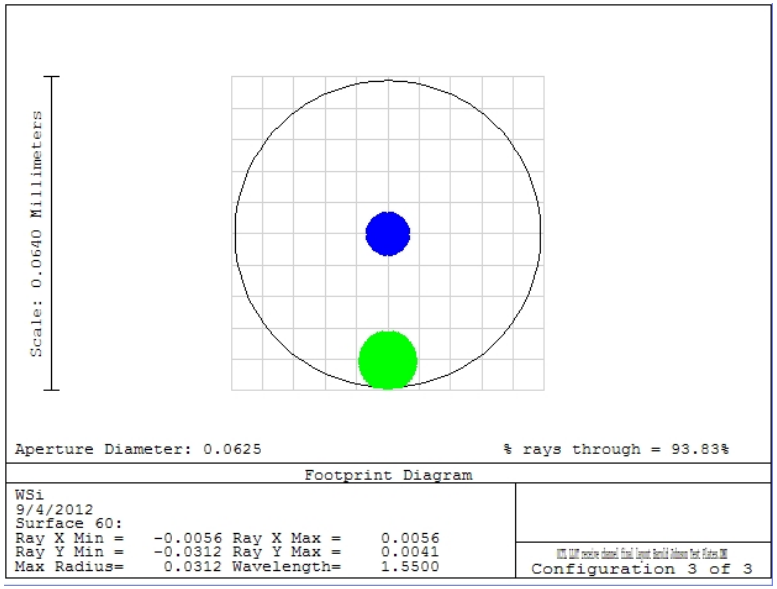


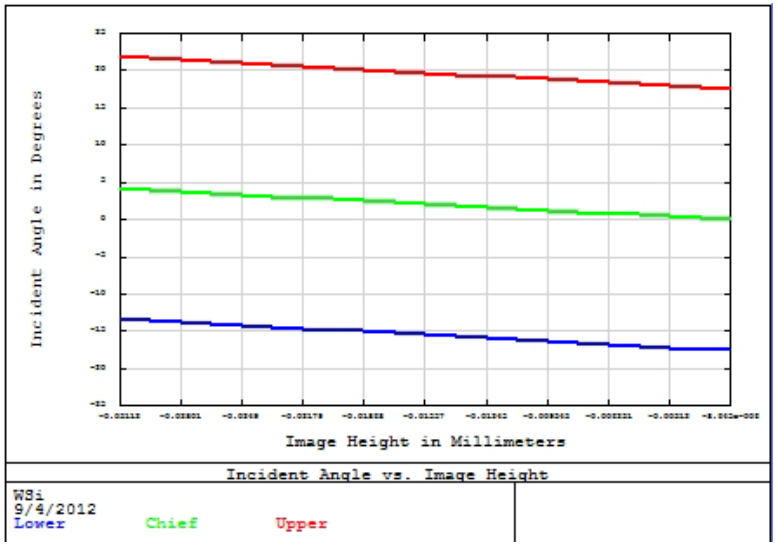
Lagrange invariant analysis:

Invariant of fiber is .275 x 62.5 um = 17.2 um radian

Maximum field stop size image-able on fiber with 100% throughput is 344 um or ~34 urad

Larger FOV (up to 50 urad) can be imaged with ~ -3 dB loss

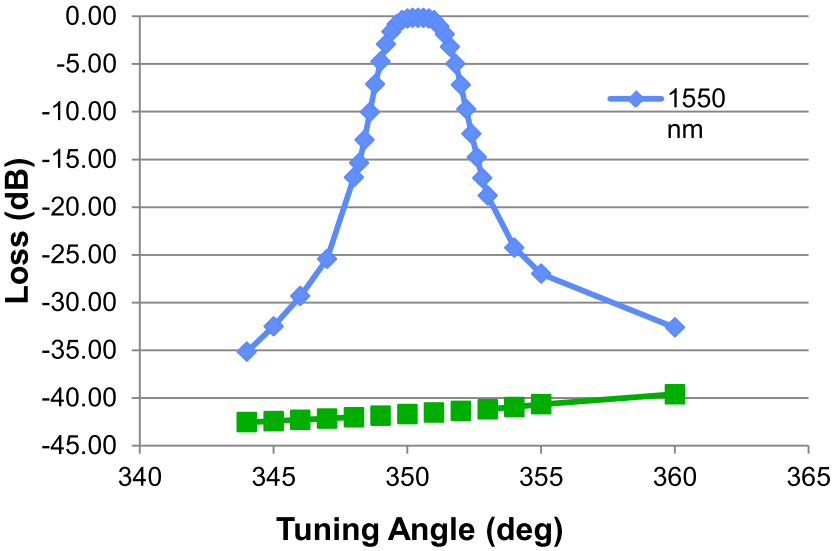


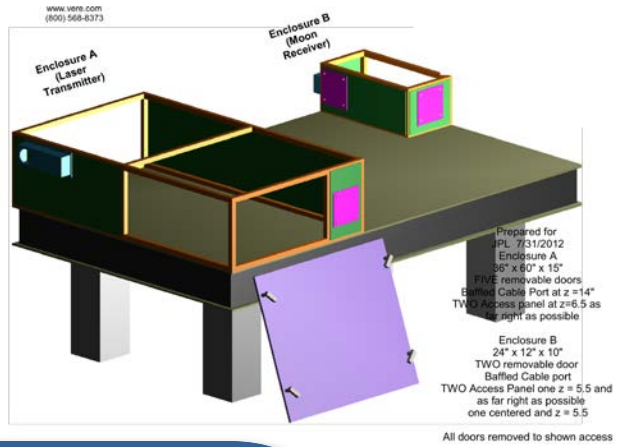


Simple and Efficient coupling to fiber-coupled data detector

TRANSMIT/RECEIVE ISOLATION

- **2-inch Dichroic mirrors**
  - **0.07 dB insertion loss at 1550 nm**
  - **initial testing shows over 40 dB of rejection at 1568 nm**
  - **Subsequent testing showed over 70 dB of rejection at 1568 nm**
- **Extensive baffling to isolate lasers and receive detectors**
  - **Filters to suppress laser ASE**
  - **Filters to suppress sky/moon background**





Design and tests support achieving 125 dB Tx/Rx isolation

LLOT OPTICS SUMMARY

Commercial laser system able to meet LLOT beacon laser requirements

- Fiber based MOPA configuration upgraded to accommodate narrow line-width

20 W cw output power at 1568 nm, kHz modulation, SMF coupled, ~ MHz linewdith

Transmit design supports LLOT operations

- Demonstrated to achieve and hold alignment through zoom
- Predicted 40-110 μrad zoom given laser specifications
- Potential for adjusting zoom range to accommodate laser variance

Receive channels meet requirements

- Meets desired FOV on pointing and data channels
- Seamless variable transition from pointing camera to data detector

System is capable of supporting demonstration

- Transmit/Receive isolation over 130 dB measured
- Sky background radiance manageable
- Isolation enclosures enhance safety and background suppression

LLOT Optical systems expected to achieve goals