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NASA Jet Propulsion Laboratory
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Laser Guide Star Adaptive Optics at Palomar Observatory

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Palomar LGSAO program goals

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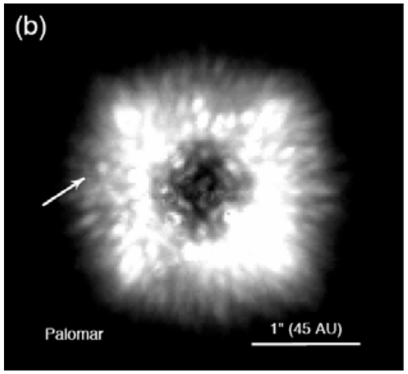
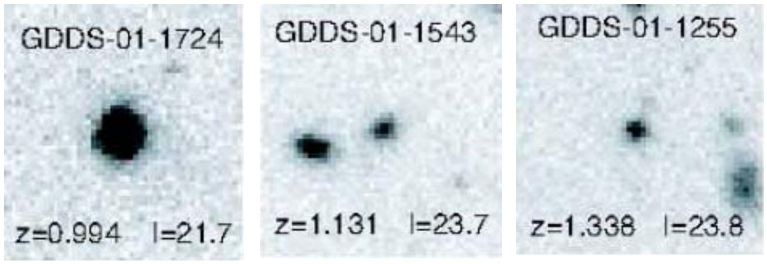
- Develop a sodium laser guide star system to extend the sky coverage of the 241 degree-of-freedom NGS AO system.
- High Strehl with moderate sky coverage.
  - 5.1 m telescope suffers little focal anisoplanatism (~89 nm)
  - High actuator density (31cm subappertures)
- Science drivers

High contrast observations



HD49197; ΔK = 8.2
(Metchev, 2005)

Visible light AO



“redshift desert” galaxies (Glazebrook *et al.*, 2003)

Palomar NGS AO system

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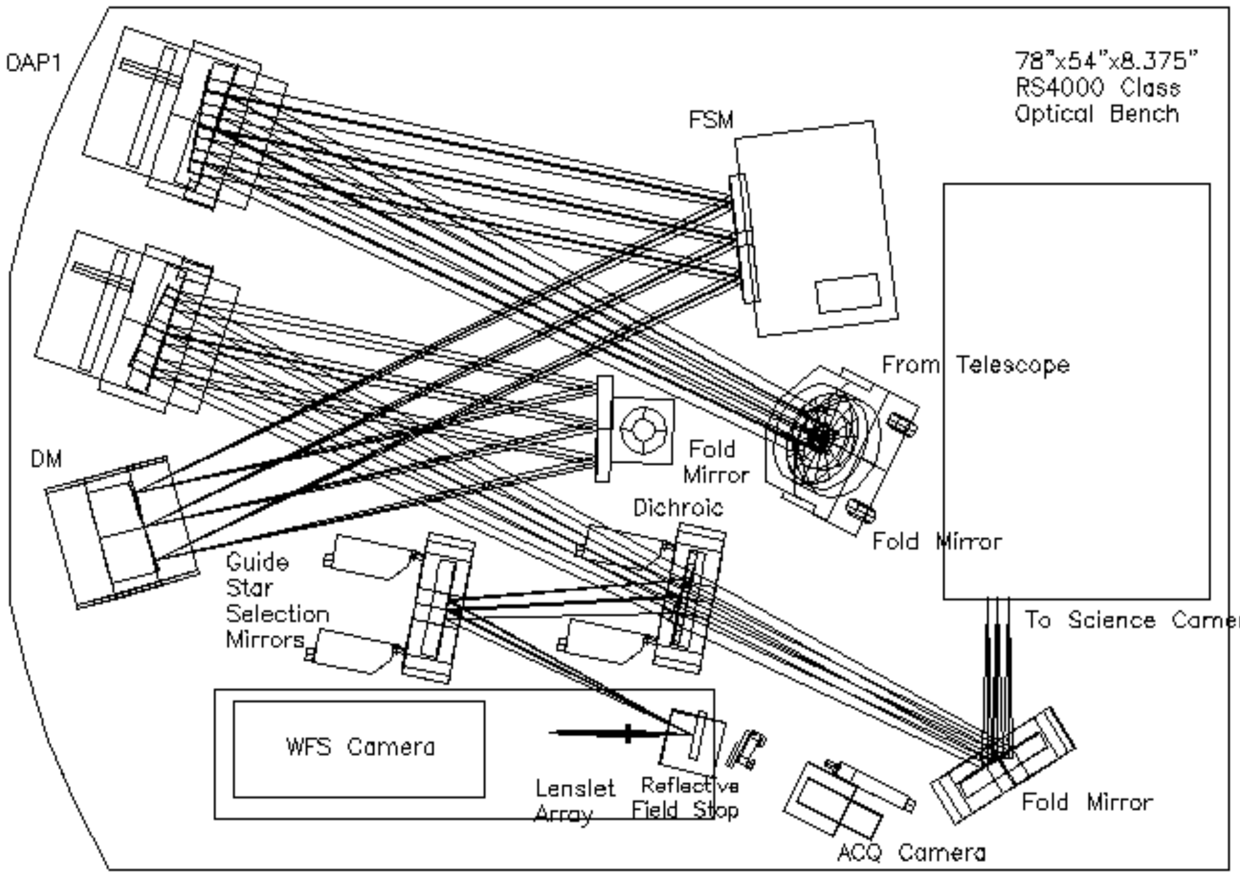
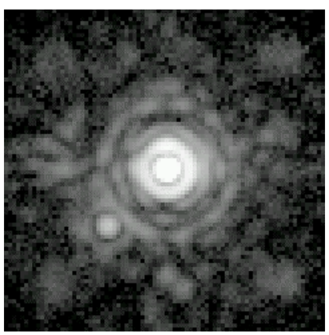
- Facility NGS AO system operational since 1999
- 241 active element Xinetics deformable mirror
- 16x16 Shack-Hartmann WFS (EEV CCD39)
- Operated at framerates up to 2 kHz.
- NGS wavefront error ~230nm RMS in median conditions (r_0 = 12 cm)





K band
Strehl = 0.80
WFE = 135 nm

Low Order NGS Wavefront Sensor

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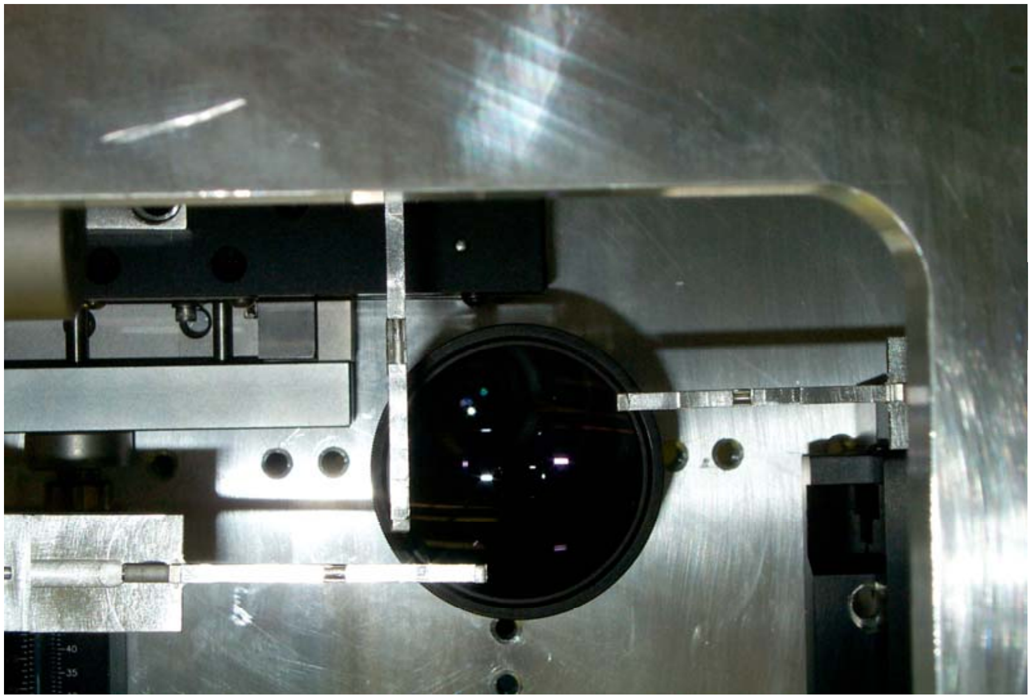
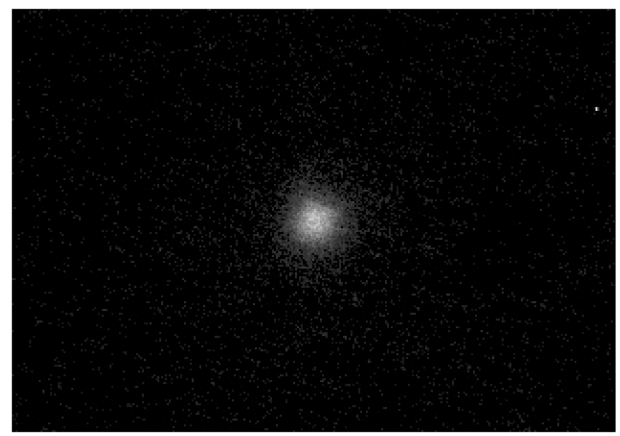


Multiple Guidestar Unit
(1 low-order WFS + 3 high-order WFS)

- 3x3 Shack-Hartmann WFS (EEV CCD39)
- Measures tip/tilt, focus, and astigmatism for stars to R~17.5 at ≥100 Hz.
- One arm of the Multiple Guidestar Unit (other arms are 16x16 S-H sensors)

Comet P/Temple 1 impact
PHARO + LOWFS tip-tilt
July 4, 2005



Laser Projection System

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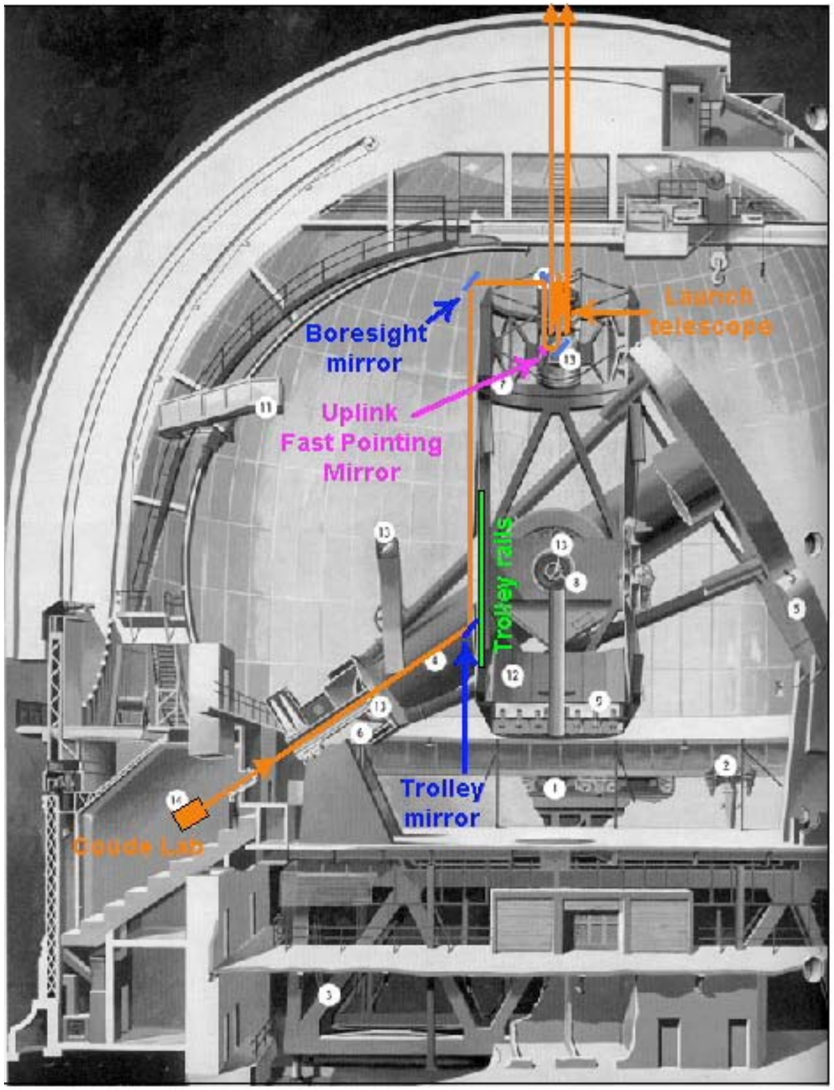

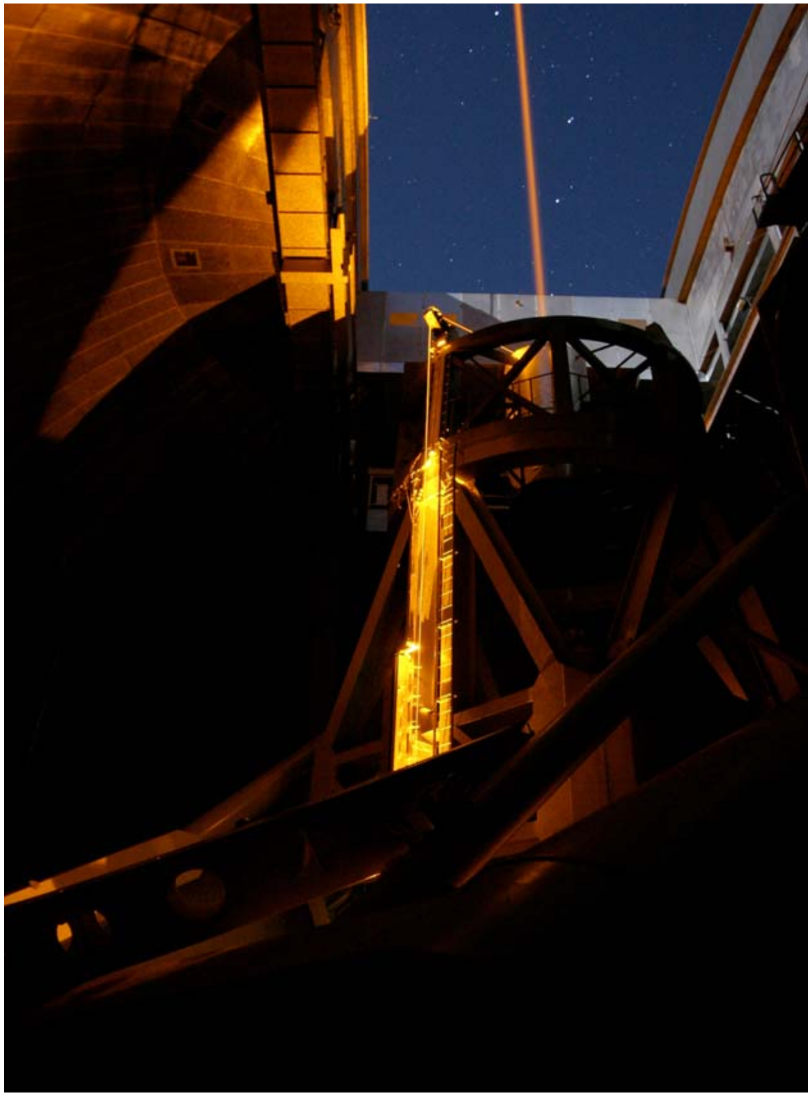

Laser projection system detailed schematic

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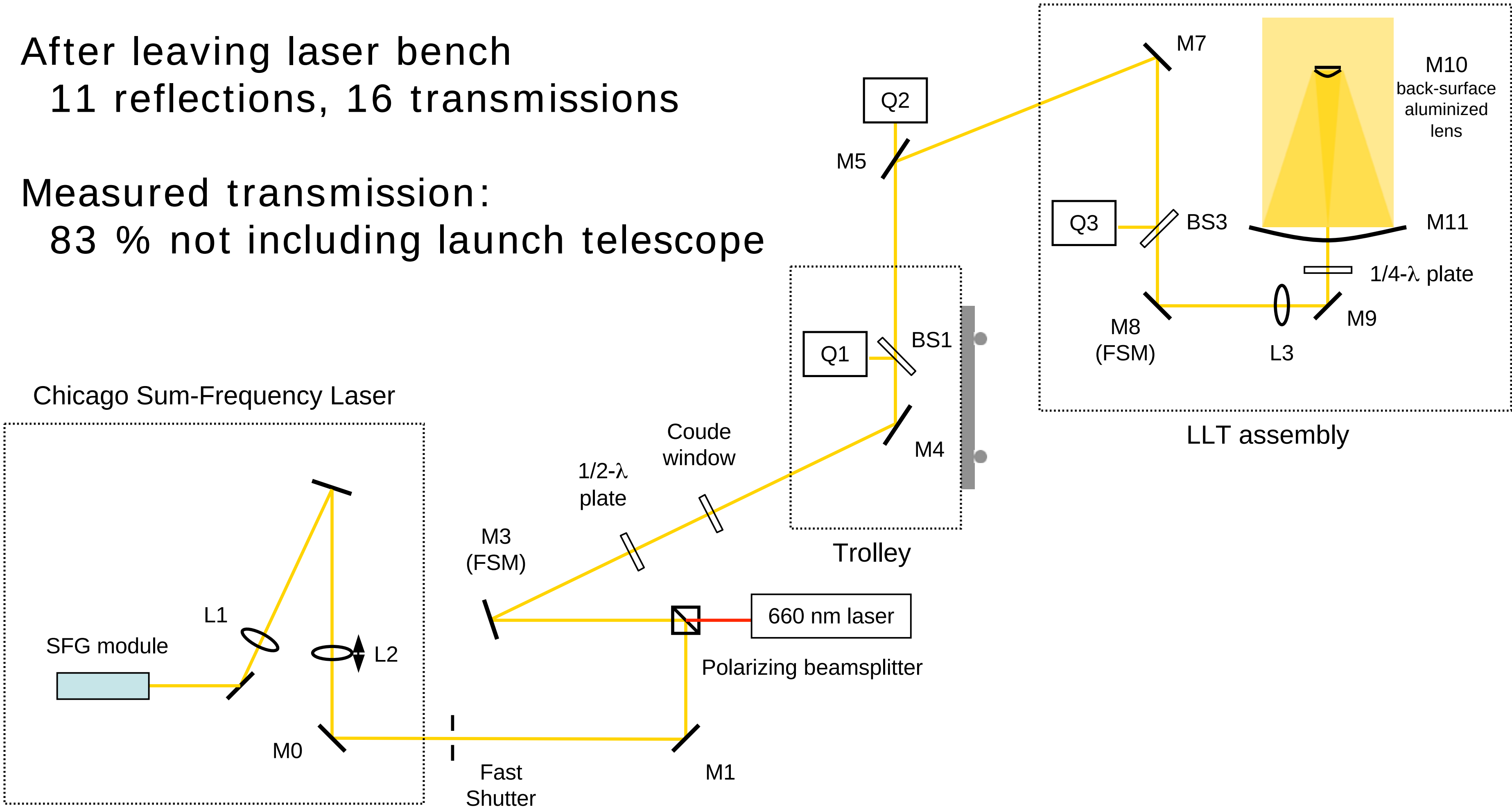
After leaving laser bench
11 reflections, 16 transmissions

Measured transmission:
83 % not including launch telescope



Laser Launch Telescope

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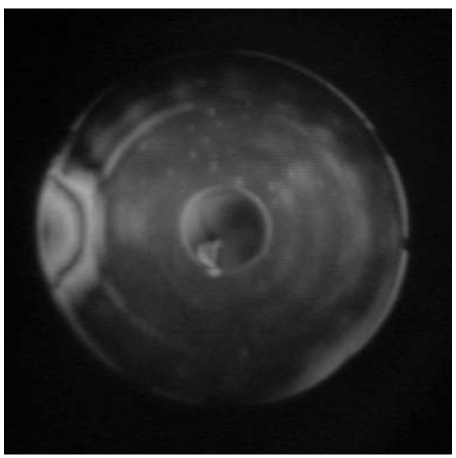
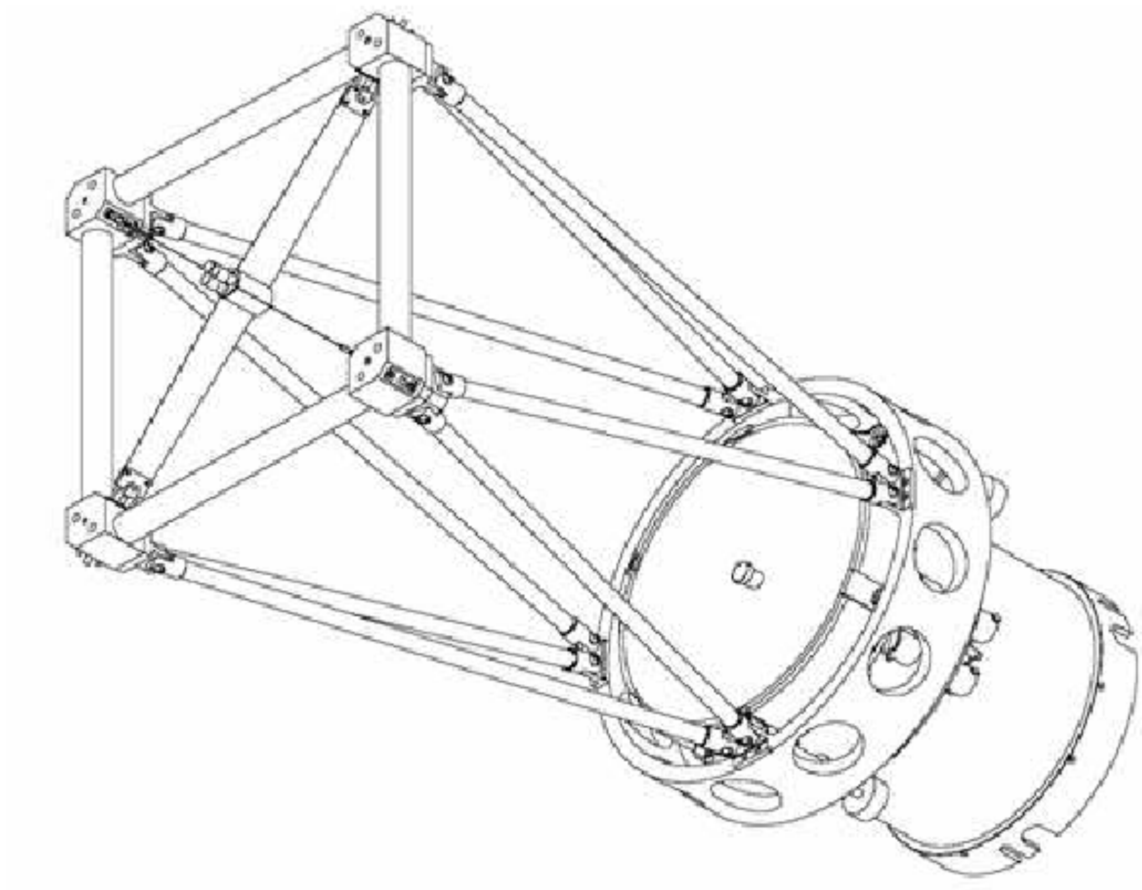
45 cm diameter, F/1.8 primary

Catadioptric secondary (0.4% obscuration ratio)

Installed on-axis behind 200” seconday.



Original primary mirror knife-edge test (11/05)



Chicago Sum-Frequency Laser

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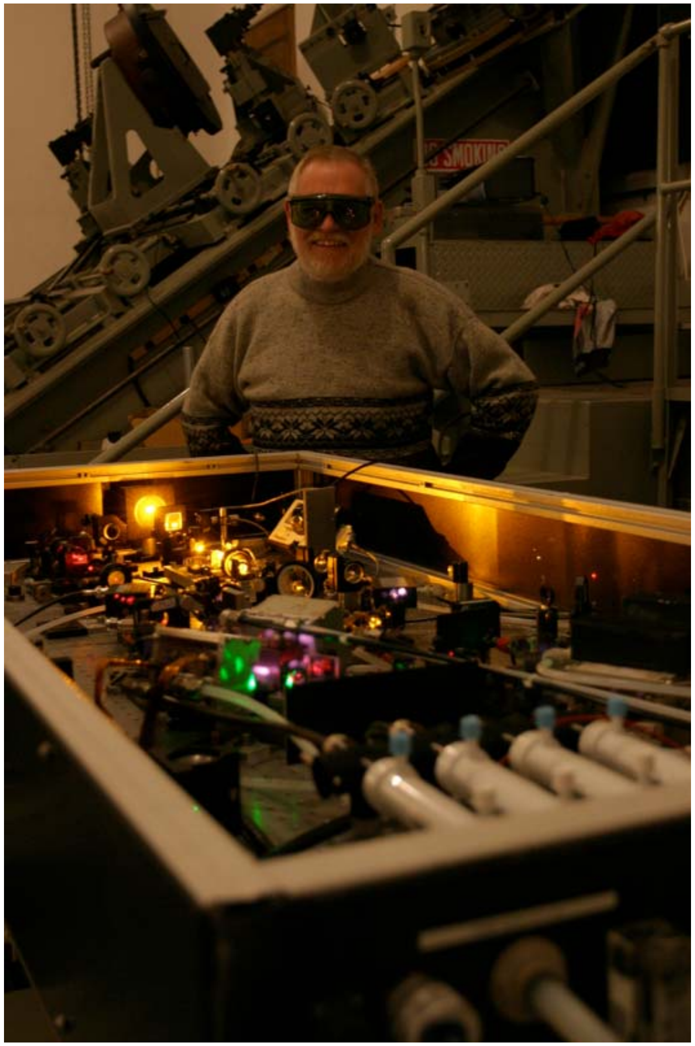

- 589nm macropulse/micropulse, mode-locked sum-frequency laser.
    - 8.5 W with high beam quality (M^2 ~ 1.05)
    - 2 GHz bandwidth
- Built at U. Chicago by E. Kibblewhite.
- First projection at Palomar October 2004.

Optical Design of Laser

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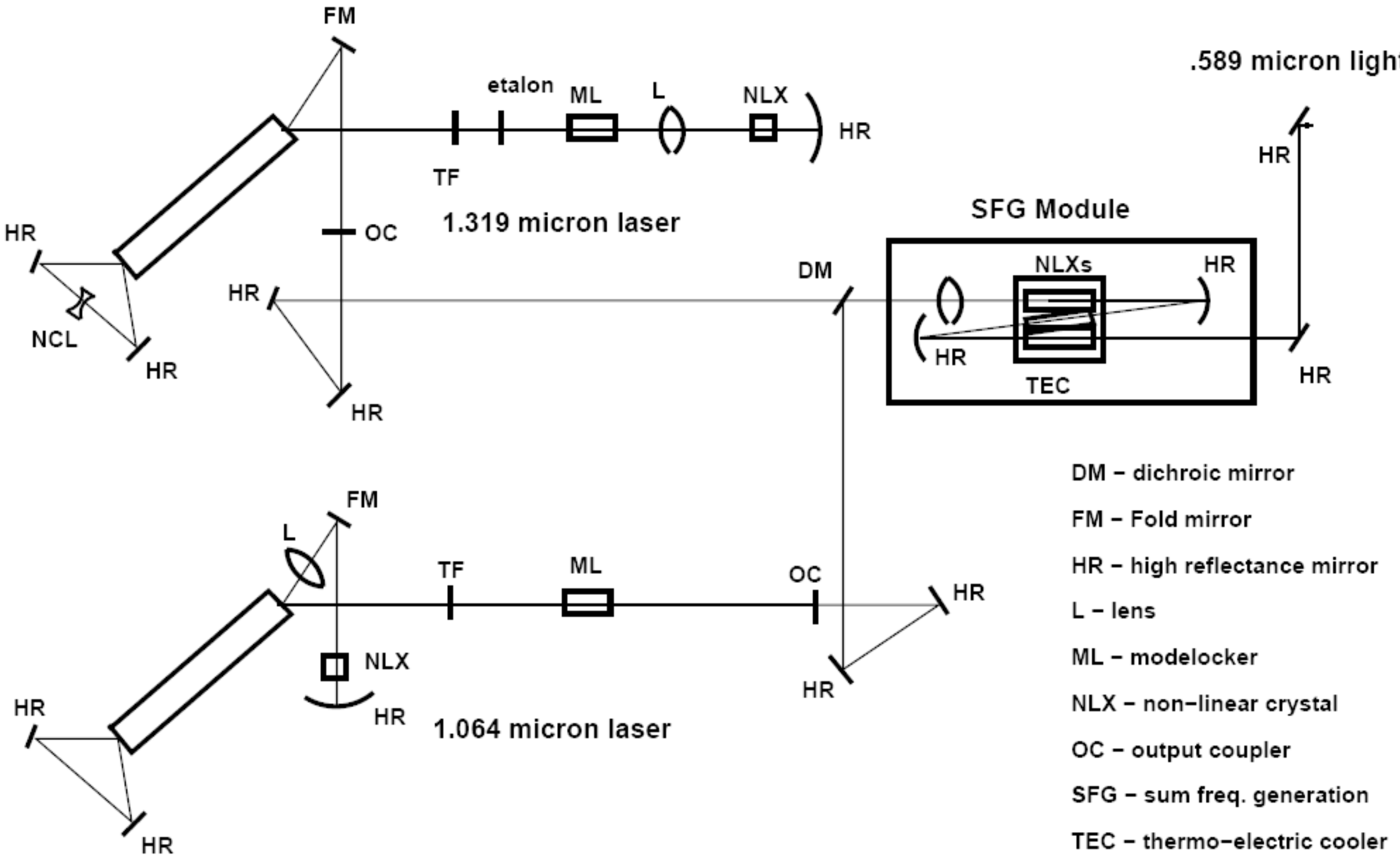

- DM – dichroic mirror
- FM – Fold mirror
- HR – high reflectance mirror
- L – lens
- ML – modelocker
- NLX – non–linear crystal
- OC – output coupler
- SFG – sum freq. generation
- TEC – thermo–electric cooler
- TF – tuning filter
- NCL – negative cylindrical lens

Chicago Sum Frequency Laser Layout

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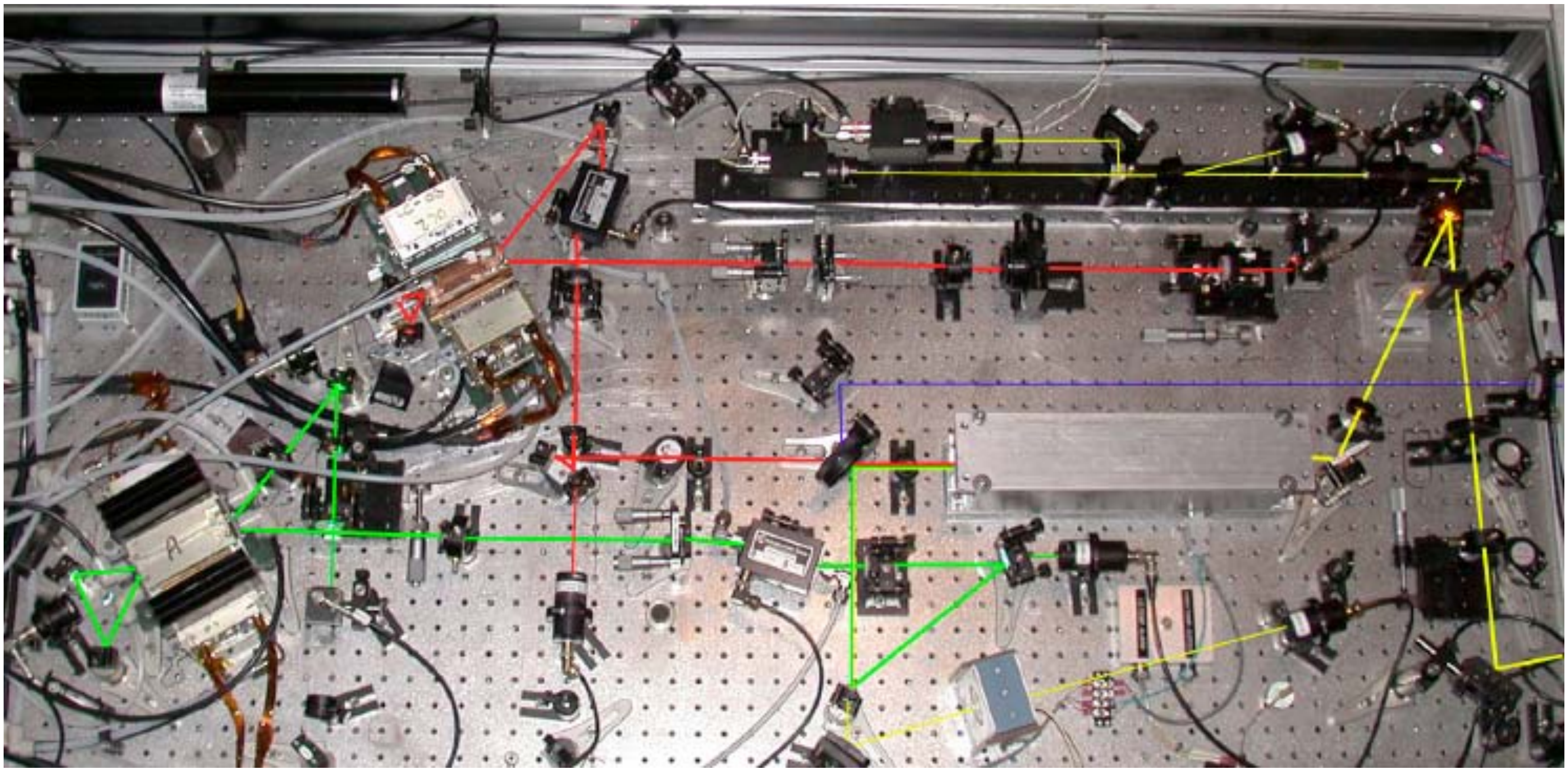

Green: 1.06 μm resonant cavity
Red: 1.32 μm resonant cavity
Yellow: 0.589 μm output

Wavefront sensor range gating

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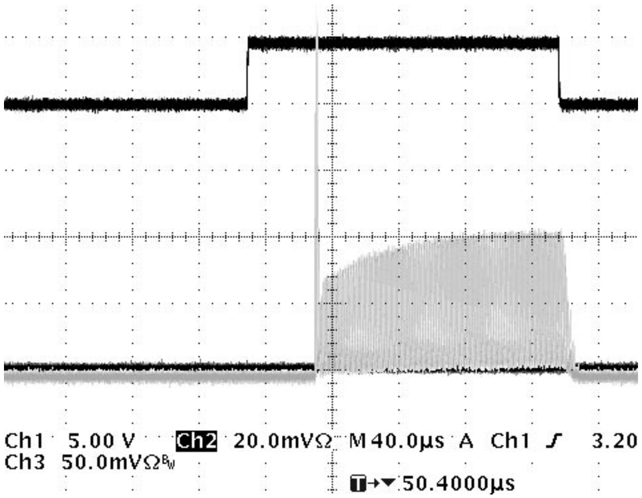
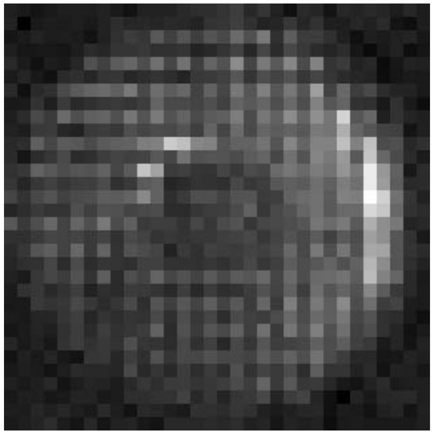
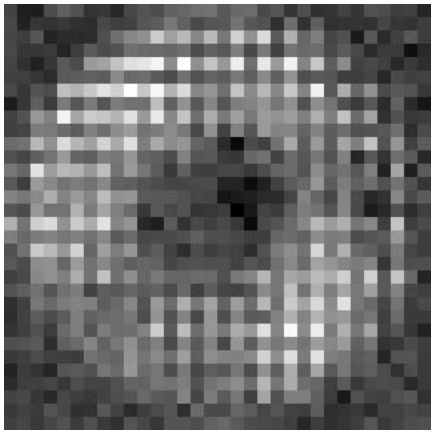


Pulse format

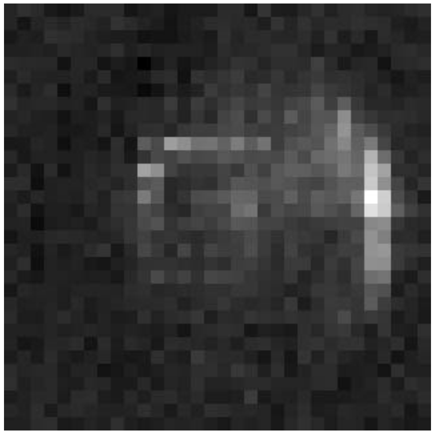
- 160 µs macropulse every 2 ms.
- Composed ot 2 µs micropulses.
- Round-trip time to Na layer is ≥590 µs
- Raleigh detected only in first ~90 µs.



No range gating (0-2000 µs)



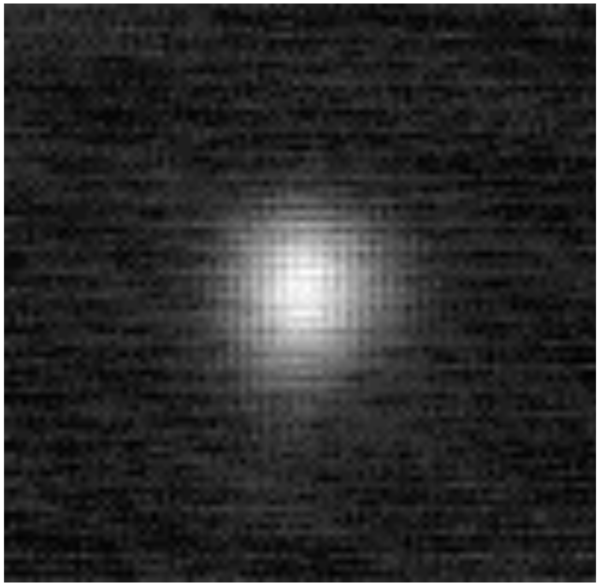
With range gating (150-2000 µs)



Difference: Raleigh and scattered light

Measured sodium return

April 24, 2006 on-sky results



- FWHM = 3.2” in 2.1” seeing
- Laser power: 5.0 W
  → ~2.5 W reaching sodium layer.
- Predicted return flux for 4×10^9 atoms cm^{-2} (d’Orgeville *et al.* 2000)

  0.34 photons cm^{-2} ms^{-1}
- Measured return flux:

  0.09 photons cm^{-2} ms^{-1}

  $V_{equiv.} = 10.0$

Possible causes: Low Na density, off of D_2 transition, polarization, bandwidth, theory?

Error budget and sky coverage

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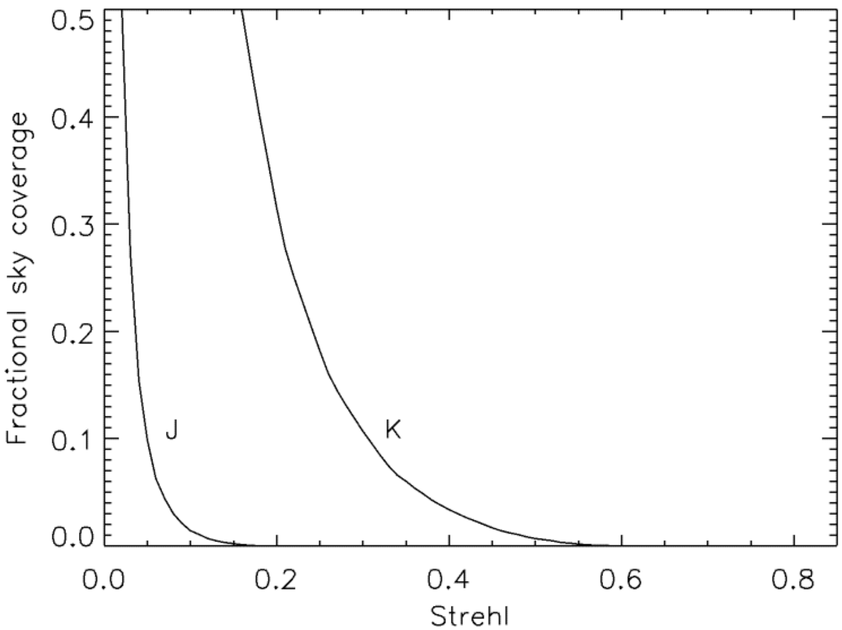
Error source (all terms nm RMS)	8.5 W LGS
Atmospheric fitting error, r_0(0.5mm) = 15 cm	73
Telescope fitting error	40
AO system internal aberration fitting error	28
Instrument fitting error	28
Focal anisoplanatism	89
Bandwidth error	76
Measurement error	78
Centroid anisoplanatism error	17
Residual aliasing (after WFS input spatial filter)	11
Tip/Tilt equiv. error (LGS: m_V=16 star on-axis)	53
Total wavefront error	**177**

On-axis error budget



LGSAO sky coverage

Status and future plans

Status

- All control loops have been tested independently.
- Performance limited by laser projection system and low photon returns.

Future plans

July Laser launch telescope primary mirror to be replaced.

Sep. Upgrade laser to 12 W.

2007 LGSAO + PHARO available for shared-risk science.

2008 SWIFT integral field spectrograph commissioning.

2009 PALM-3000 commissioning.

- 3217 active element “tweeter” DM.
- 62x62, 31x31 Shack-Hartmann wavefront sensor.
- New FPGA/DSP wavefront processor.

Related talks and posters

[6272-196] R.G. Dekany *et al.*, *PALM-3000: visible light AO on the 5.1-m telescope.*

[6272-188] V. Velur *et al.*, *Multiple guide star unit: Palomar's tomograph.*

[6272-108] M.C. Britton *et al., Wide-field self-referenced AO observations at Palomar.*

[6276-30] R.M. Smith, *Noise and zero point drift in 1.7µm cutoff detectors for SNAP.*

[6269-132] N.A. Thatte *et al., SWIFT: an adaptive optics assisted I and z band integral field spectrograph.*

[6273-100] M. Tecza *et al., SWIFT image slicer: large format, compact, low scatter image slicing.*