20 W and 50 W Guidestar Laser System Update for the Keck I and Gemini South Telescopes

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ABSTRACT

Lockheed Martin Coherent Technologies has developed 20 W and 50 W commercial solid-state sodium beacon Guidestar Laser Systems (GLS) for the Keck I and Gemini South telescopes, respectively. This work represents a critical step toward addressing the need of the astronomical adaptive optics (AO) community, including multi-conjugate AO and AO tomography for future extremely large telescopes. This paper describes the status of GLS for the Keck I and Gemini South telescopes. The design and experimental results of the laser oscillators, amplifiers and sum-frequency generator will be discussed.

1. INTRODUCTION

Deployment of guidestar laser systems (GLS) on large telescopes is continuing[1], and the scientific results achieved so far[2,3] demonstrate the benefits of the improved AO system performance and sky coverage that result from using a 589 nm wavelength laser to produce an artificial reference or guidestar in the mesospheric sodium layer. Two new lasers are under development by Lockheed Martin Coherent Technologies (LMCT), one operating at 20 W for the Keck I telescope at the W. M. Keck Observatory, and one for the Gemini Observatory's Gemini South facility. These lasers represent an evolutionary step in development based on the 12 W guide star laser delivered over a year ago to the Gemini North facility[4].

The 20 W and 50 W Guidestar laser systems are currently on track to demonstrate all of their performance parameters and will be installed at the Keck I and Gemini South telescopes, respectively. The 20 W and 50 W systems use Lithium Triborate (LBO) for Sum Frequency Generation (SFG) from the output of two diode-pumped Nd:YAG lasers. The lasers are based on Nd:YAG oscillators mode-locked at 77 MHz with 450 ps pulses and generating ~1.0 GHz spectral line widths at 1064 nm and 1319 nm. The oscillators are followed by several amplifiers to generate in excess of 160 Watts of combined 1064 nm and 1319 nm pump light for the SFG. The SFG is single pass and non-critically phase matched[5]. The output wavelength is locked to a reference sodium cell providing active feedback for sodium line resonance. Wavelength tuning is accomplished using an intra-cavity etalon in the 1064 nm oscillator.

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2. SYSTEM REQUIREMENTS OVERVIEW

The systems requirements for the GLS were presented in a previous paper[6] and are summarized here. LMCT will meet the requirements for a laser at the Keck I telescope by providing 20 W of 589 nm laser light with temporal, frequency, and spatial profiles tailored to the mesospheric sodium layer absorption line. These and other optical requirements are summarized in Table 1 below. The output pulse repetition rate is 12 ns, closely matching the sodium atom's upper state lifetime of 16 ns, allowing for substantial decay from the exited state before the next pulse arrives. The laser pulses have a nominal duration of ~0.5 ns, resulting in a ~1.0 GHz spectral bandwidth. The laser output's central frequency is compared to the emission lines of sodium using a sodium reference cell on the laser's optical bench. A wavelength tuning system is provided to ensure maximum return from the mesospheric sodium. To enable subtraction of the Rayleigh backscatter, the GLS will be capable of rapidly moving >5 GHz off of the sodium resonance and then back on again without changing output power. The output beam quality will have a divergence (M^2) of less than 1.4 times the diffraction limit, resulting in a near diffraction limited spot size in the mesospheric sodium layer.

The Gemini South GLS system has the same requirements as the Keck I system except that the Gemini South system requires 50 W of laser power that will be used to generate a constellation of 5 guidestars. In the original design this 50 W output was split into five beams of 10 W each but the system has now been changed to output a single 50 W beam with the division into 5 beams accomplished in the laser projection system mounted on the top end of the Gemini South telescope. To achieve this higher power, the Gemini South system builds on the scalable LMCT laser architecture by adding more amplifier modules to the IR lasers. The differences between the Gemini South and Keck I systems will be noted in the text.

Each system will be located within a Class 10,000 clean room on a Nasmyth platform at each telescope and will dissipate less than 500 W of heat to the ambient. Both the laser bench and the electronics racks are designed to withstand the vibration, seismic, and temperature conditions of the observatory summit locations. Table 2 summarizes these and other electrical and mechanical requirements. The GLS systems meet the weight and size requirements for Keck I and Gemini South.

Description	Units	Keck	GS	Comments
Power at 589 nm	W	**20**	**50**	minimum
Power Stability - short term	%	**10**		peak to peak over 5 min at 800 Hz sample rate
Power Stability - long term	%	**5**		RMS over 12 hrs at 800 Hz sample rate
Beam Quality, M2	-	**1.4**		maximum
Beam Quality Stability	%	**10**		maximum
Frequency Stability	MHz	**100**		maximum, peak to peak
Spectral Bandwidth	GHz	**1.5**		maximum; 1.0 GHz nominal
5 GHz Frequency Shift Time	s	**30**		maximum; for Rayleigh calibration
Pointing Stability - Transverse	mm	**±0.5**		maximum
Pointing stability - Angular, short term	urad	**20**		maximum, RMS over 1 sec
Pointing stability - Angular, long term	mrad	**±0.4**		maximum, peak to peak over 30 min
Linear Polarization Purity	%	**95**		minimum

Table 1: Summary of Optical Performance Requirements for the Keck I and Gemini South GLS

Description	Units	Keck	GS	Comments
Ambient Operating Temperature, long term	C	**-10 to + 20**		typcially 9C for GS; 0C for Keck
Ambient Operating Temperature Range, 12 hrs	C	**±2**		
Heat Dissipation to Ambient	W	**500**		maximum
Heat Dissipation to Coolant	kW	**10**	**15**	maximum
Coolant Flow	lpm	**20**	**40**	maximum
Laser Enclosure Dimensions	mm	**2320 H x 2750 W x 1150 D**	**2320 H x 3660 W x 1150 D**	Includes clearance above and below enclosure
Electrical Enclosure Dimensions	mm	**2320 H x 1270 W x 980 D**		
Mass	kg	**2350**	**2600**	maximum
Vibration	g2/Hz	**1.0E-05**		Add'l requirements per Keck vibration curve
Electrical Current @ 208V	A	**40**	**60**	maximum
AC Power Frequency	Hz	**60**	**50**	nominal
Power Factor	-	**0.6**		minimum
CPU Usage	%	**50**		maximum
Startup Time	min	**30**		maximum

Table 2: Summary of mechanical, electrical, and other requirements for the Keck I and Gemini South GLS

3. 20 W AND 50 W GUIDESTAR LASER SYSTEMS

Figure 1 shows a block diagram for the GLS. The 20 W and 50 W systems utilize diode pumped Nd:YAG 1064 nm and 1319 nm stable oscillators with identical configurations. These oscillators are mode-locked to 77 MHz using an acoustic-optic modulator and produce 350 ps to 600 ps pulse widths. They have a line width of ~1.0 GHz and the ability to continuously tune +/- 20 GHz. Their near-diffraction-limited beam quality is measured to be $M^2 < 1.1$ and to have depolarization ratios < 60:1. Output power is 22 to 26 W for the 1064 nm oscillator and 12 to 15 W for the 1319 nm oscillator. All of these specifications have been demonstrated simultaneously. The oscillators in the Gemini South and Keck I systems have been upgraded from the Gemini North system design. The frequency control for locking to the Sodium absorption line is now performed using a PZT driven etalon in the 1064 nm for rapid tuning and characterization at >20 Hz scan rates. The Gemini North design used a temperature-controlled etalon with a much slower frequency slew rate on the order of tens of seconds. The mode locker control is now performed by position control of a high reflectivity mirror utilizing an encoder to monitor the position of the mirror at all times, preventing drift that can lead to mode lock pulse stability issues. We have also incorporated improved mechanical mounts for the diode pump delivery optics that have resulted in better long-term oscillator stability and improved maintainability.

The amplifiers used in the system are re-imaging waveguide amplifiers developed at LMCT[7]. The waveguide amplifier modules for 1064 nm and 1319 nm are identical except for end-face coatings and waveguide length. The 1319 nm waveguides require AR coatings at 1064 nm to help suppress parasitic 1064 nm lasing. The waveguide gain optics utilizes LMCT's patented Talbot reimaging technology in a double-pass, single end-pumped configuration. The waveguides are diode pumped with a three bar, 300 W stack centered at 799 nm and focused into the end of the waveguides. Image relay optics are utilized between stages of amplification.

The one dimensional waveguide amplifier requires optics to correct for first order aberrations (primarily astigmatism) in the unguided dimension. As a result of gain saturation effects, the amplified output beam intensity profile from the amplifier becomes a super-Gaussian. We have demonstrated a M^2 of 1.5 in the unguided dimension from our waveguide amplifiers. The guided dimension retains near diffraction-limited performance. During testing and integration, "Power In the Bucket" (PIB) measurements were used to quantify the beam quality of the WAMs due to the super-Gaussian beam profile. PIB is a ratio describing the sum of the power in the far-field central lobe of the beam divided by the total far-field power[8].

The 20 W Keck I system uses one 1064 nm waveguide amplifier and two 1319 nm waveguide amplifiers. The 1064 nm beam is amplified to 75 W and has a far-field profile with a measured PIB of 0.62. The 1319 nm beam was amplified to 45 W with a measured PIB of 0.68. The optical layout of the Keck I system is shown in Figure 2.

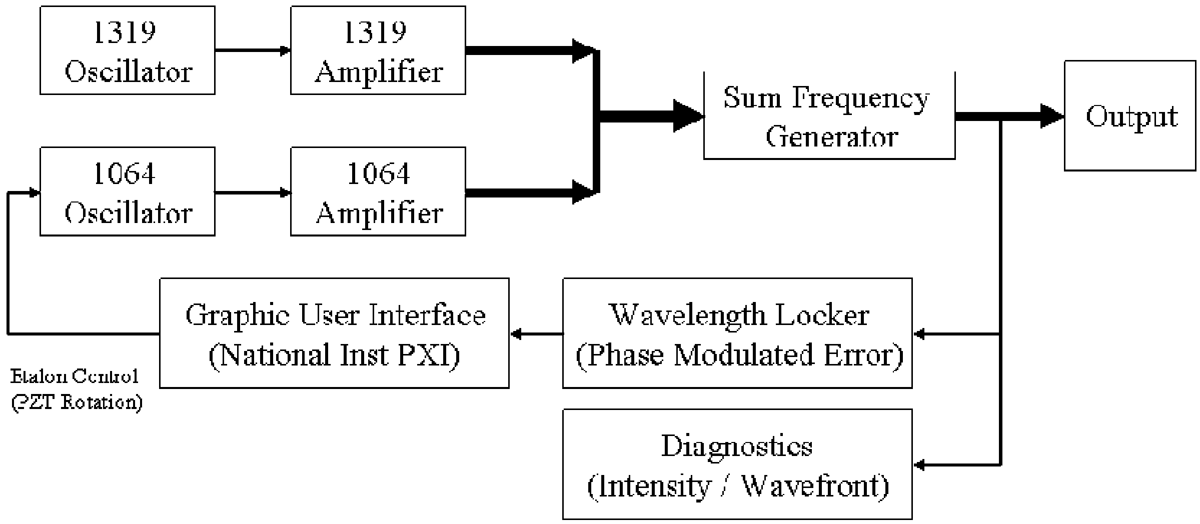

Figure 1: GLS block diagram

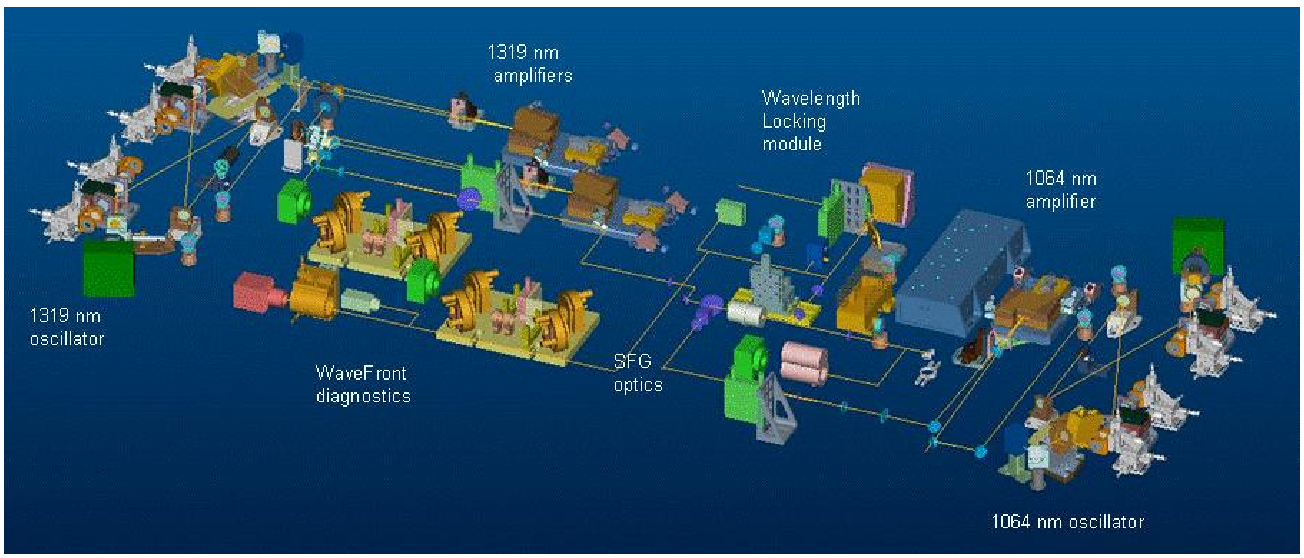

Figure 2: Keck I laser system optical layout

The 50 W Gemini South system uses two 1064 nm waveguide amplifiers and three 1319 nm waveguide amplifiers. The 1064 nm beam is amplified to 135 W with a measured PIB of 0.60. The 1319 nm beam is amplified to 76 W with a measured PIB of 0.63. The 50 W system uses an extra waveguide amplifier module for each beam and has increased non-uniform gain in the unguided dimension compared to the 20 W system. The Gemini South laser layout is shown in Figure 3. The far field cross-sections of the 1319 nm beam at 76 W are shown in Figure 4.

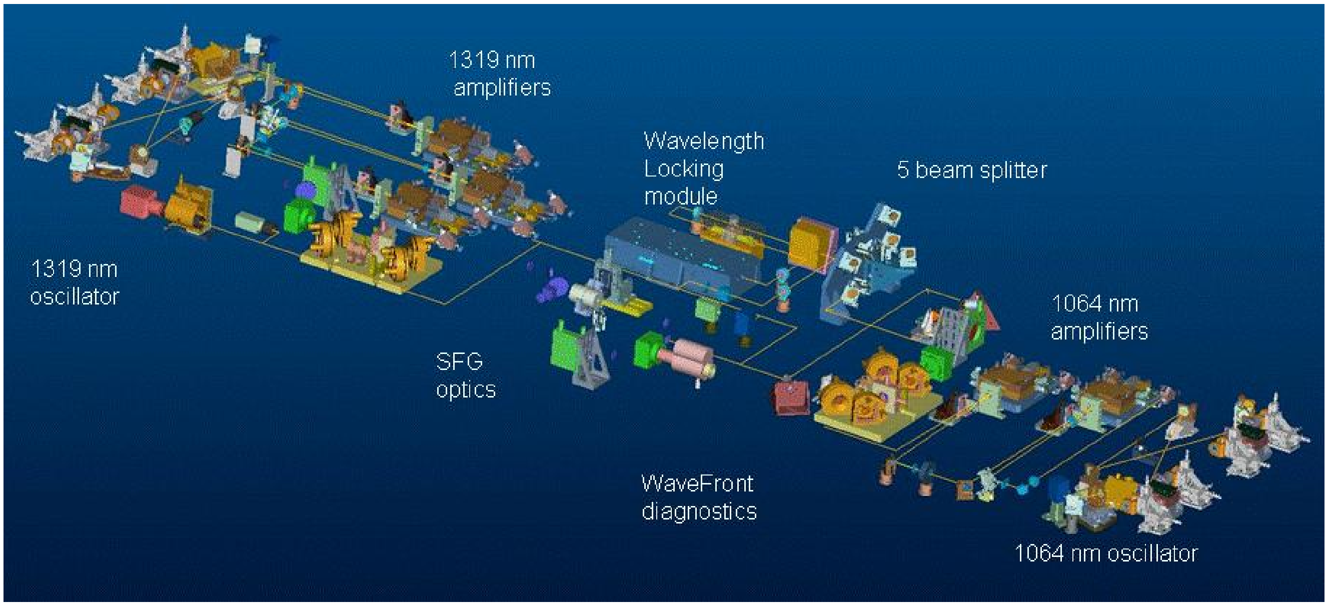

Figure 3: Gemini South laser system optical layout

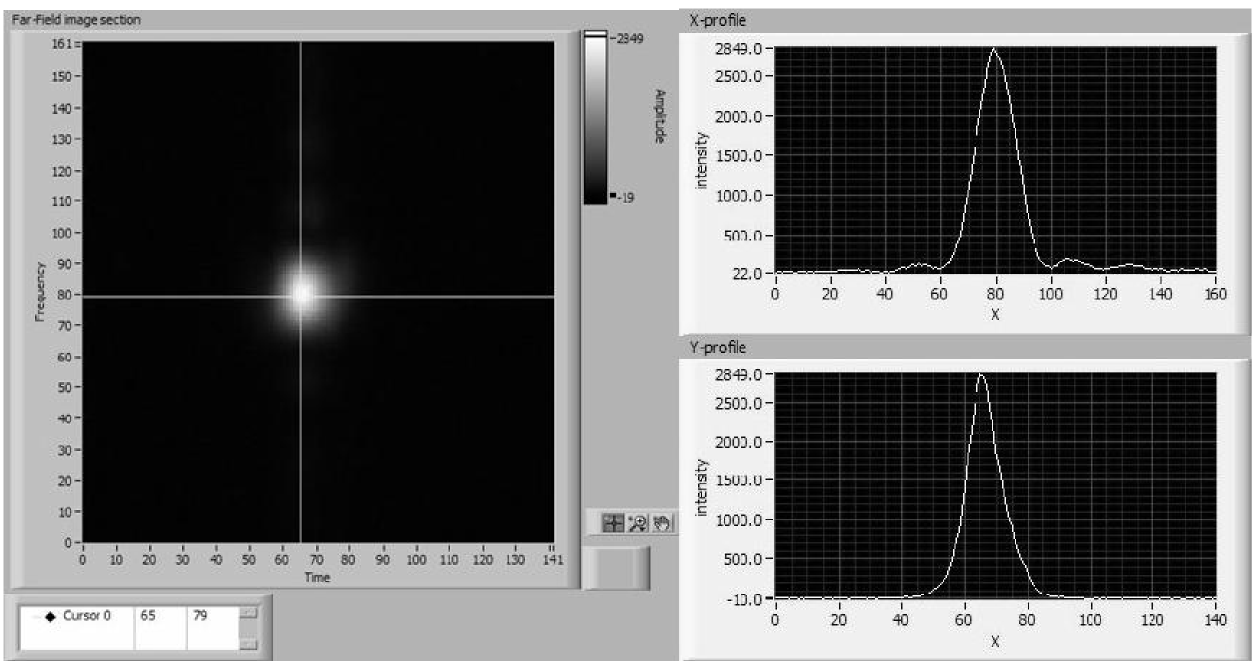

Figure 4: Far field profile, 76 W at 1319 nm

The 589 nm output is produced by SFG using single-pass focusing of the 1064 nm and 1319 nm beams through an LBO crystal and is identical for the 20 W and 50 W systems. The 3 mm x 3 mm x 50 mm LBO crystal is AR coated for 1064 nm, 1319 nm, and 589 nm. The crystal temperature is controlled using a commercial off the shelf oven to a temperature of +/- 0.1 ºC. The average temperature of the crystal oven is nominally 40 ºC to provide non-critical phase-matched operation of the LBO crystal.

Servo control of the 589 nm frequency is obtained by tuning the 1064 nm oscillator. The servo error signal is generated using absorption in a sodium gas reference cell. Each oscillator contains an etalon with a free spectral range of 50 GHz that is temperature and angle tuned. The wavelength locker servo angle tunes the etalon in the 1064 nm oscillator with a

PZT actuator. The etalon in the 1319 nm oscillator is tuned by changing temperature and adjusting its static tip/tilt mount. The PZT actuator can tune the 1064 nm oscillator +/-20 GHz and is used to tune away from the sodium line. This functionality provides a means of observing the Rayleigh back scattering so that it can be subtracted from the return light for AO wavefront sensing calibration.

4. SFG EXPERIMENTAL RESULTS

The 1064 nm and 1319 nm beams are routed and focused to 60 μm FWHM at the center of the LBO crystal. The pump beam transfer optics and SFG oven design provide the degrees of freedom needed to optimize the beam overlap and maximize 589 nm power conversion. Polarizer and wave plate controls are provided in the 1064 nm and 1319 nm pump beams to allow photon balancing and data collection. The 20 W Keck I system has demonstrated 22 Watts output at 589 nm. Power stability was measured to be within ±5% over several hours. The Gemini South system has demonstrated 55 Watts at 589 nm. The 589 nm output power and conversion efficiency versus IR input power is shown in Figure 5. Both demonstrations used a non-photon-balanced amount of 1064 nm and 1319 nm pump light to produce the highest yellow power results.

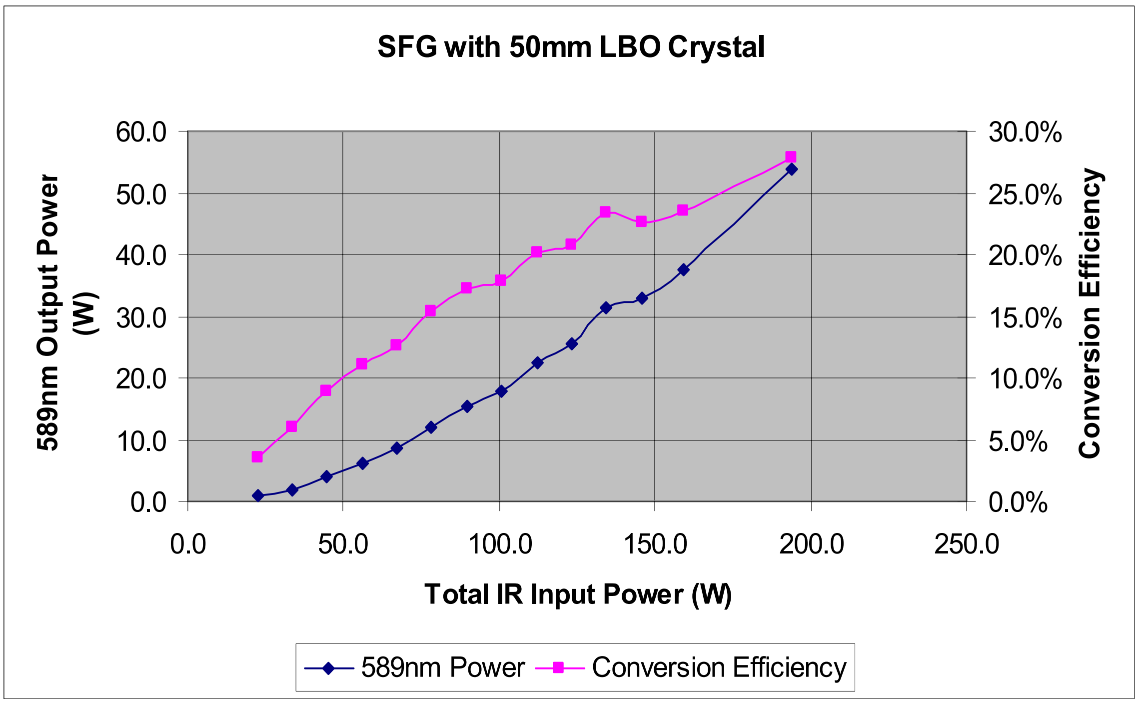

Figure 5: 589 nm power and conversion efficiency vs. IR input

The measured M^2 for the 20 watt system was 1.3 at 22 watts measured via conventional beam propagation. This was in good agreement with data taken using a Wavefront Sciences Shack-Hartmann wavefront sensor, which measured an M2 of 1.37, averaged over two axes. Figure 6 shows the far field profile of the 589 nm beam at 22 watts.

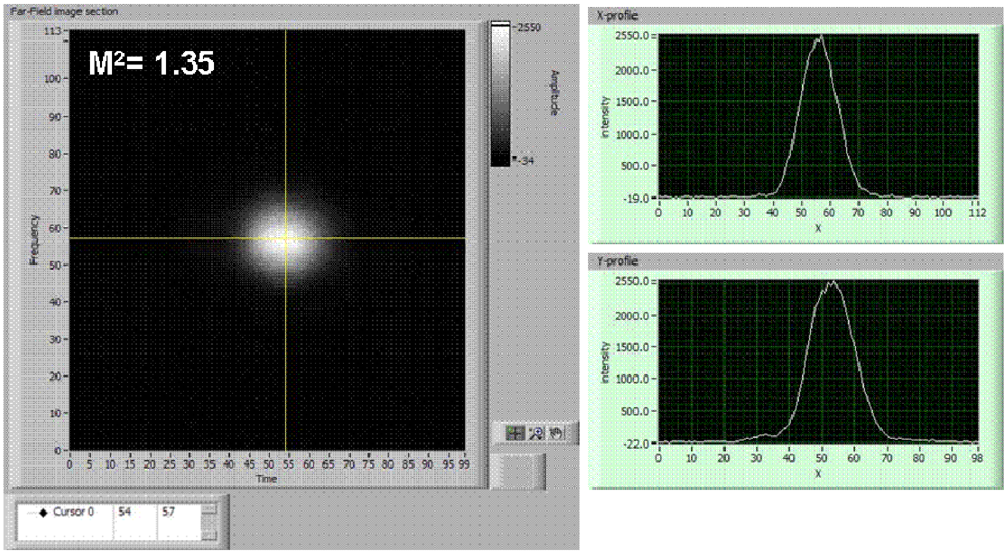

Figure 6: Far Field Beam quality data for the Keck I GLS

5. GEMINI SOUTH AND KECK I GLS CURRENT STATUS

LMCT is nearing completion of the build for the Gemini South and Keck I GLS. The Gemini South electronics rack (enclosure) is complete and tested; the laser bench enclosure is assembled, and the optical bench fully populated. The laser optical components are undergoing the final alignment before we begin acceptance testing. The Keck I laser enclosure is under construction and the optical bench is being populated. The photographs below in Figures 7 to 9 show the laser enclosures and electronics rack in assembly at our facility in Colorado. . Both laser systems are expected to be delivered in the second half of 2008.

6. CONCLUSION

Lockheed Martin Coherent Technologies will soon deliver two GLS, one at 20 W, and one at 50 W. The laser technology uses 1064 nm and 1319 nm solid-state diode-pumped lasers and SFG in nonlinear LBO crystals. A servo control system is used to control the output wavelength for resonance with the sodium D2a line.

In the future, LMCT plans to improve our Guidestar technology with ruggedized IR laser designs. We plan to develop nonlinear optical design tools that will consider spatial thermal-optical effects in the nonlinear crystal and IR pump beams with unique spatial characteristics. LMCT is currently working with the astronomy community to determine the optimum pulse format for sodium beacon Guidestar laser systems.

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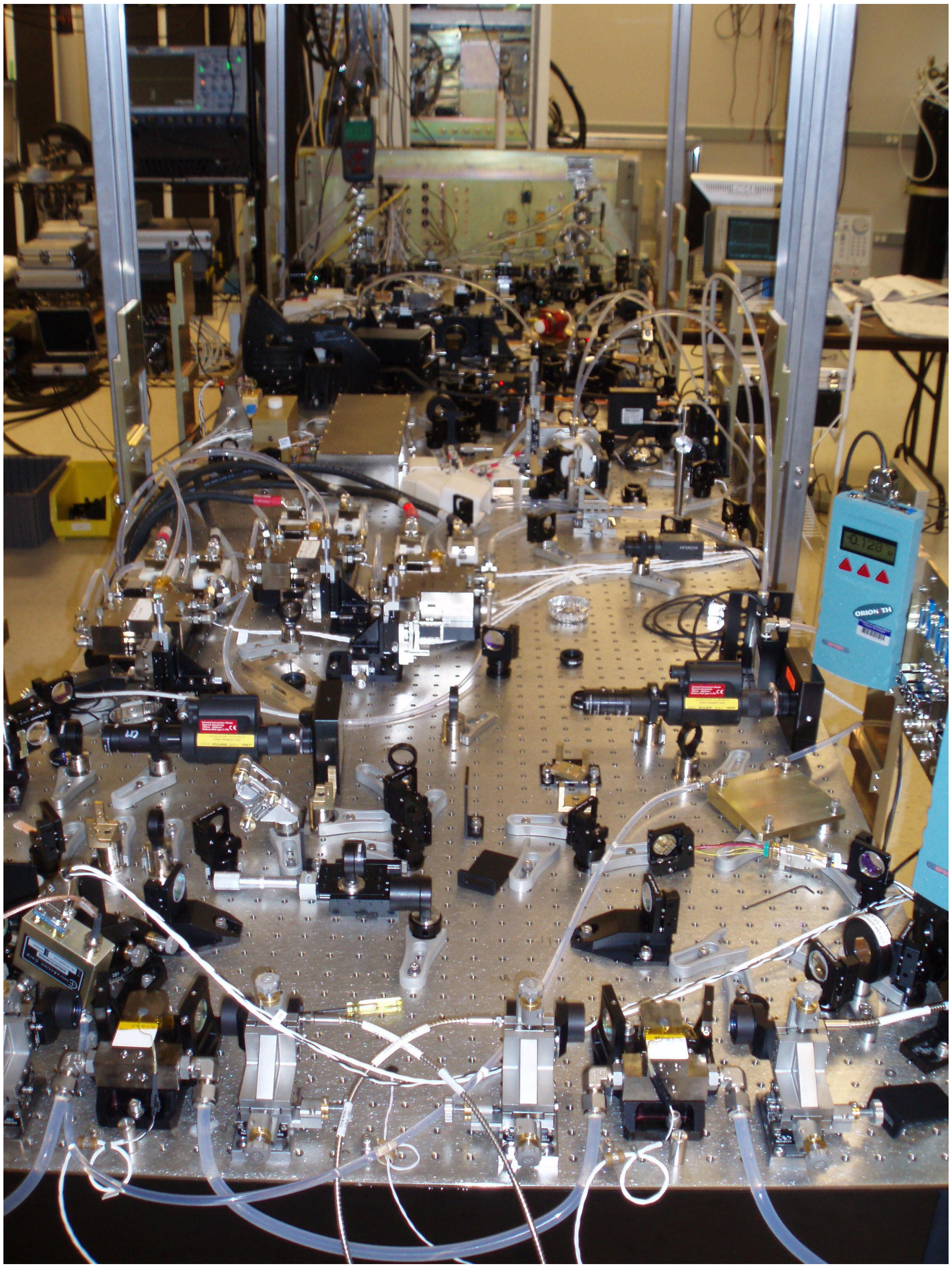

Figure 7: Gemini South laser bench with 1319 nm oscillator in foreground

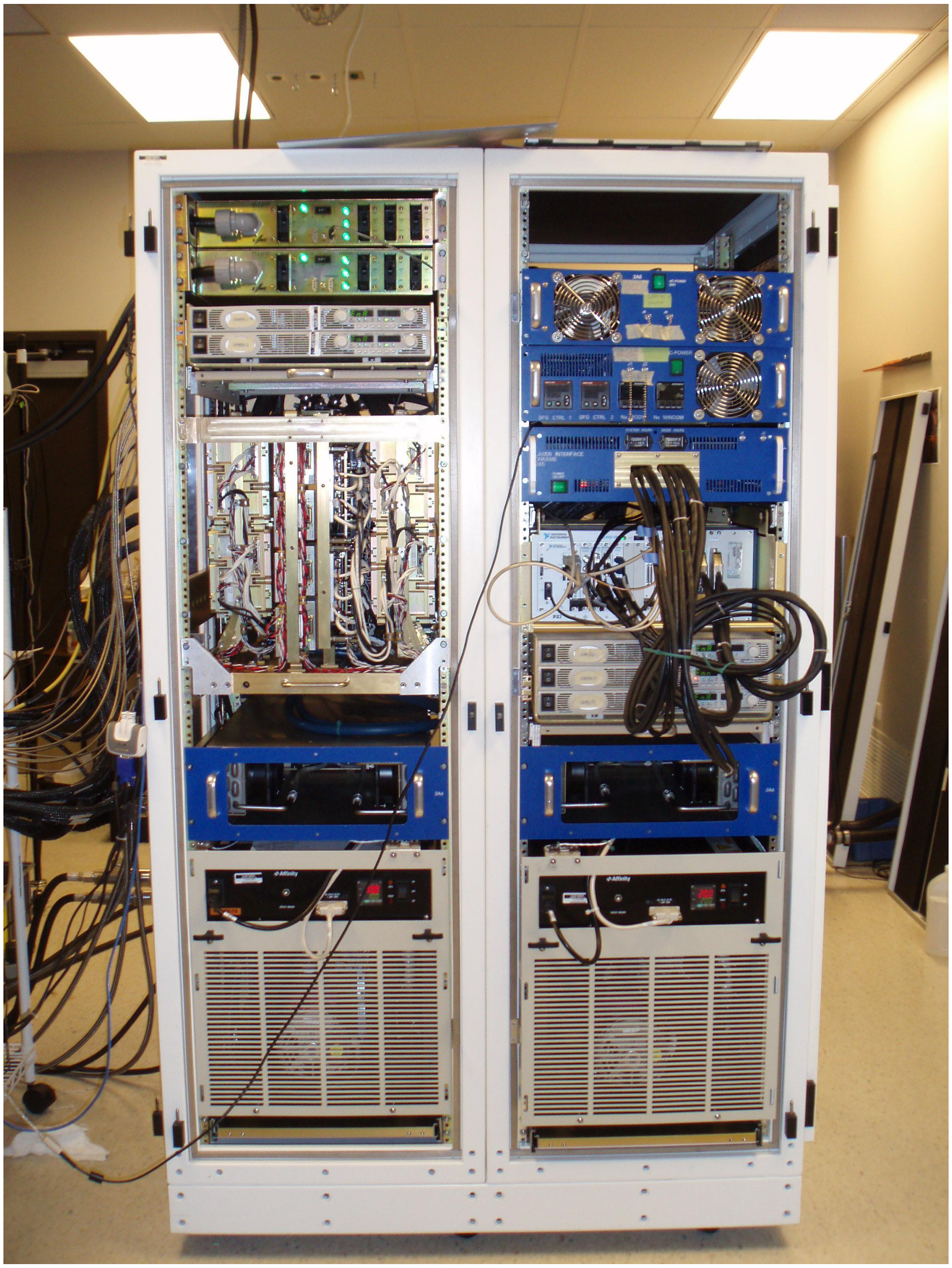

Figure 8: Gemini South electronics enclosure with doors removed

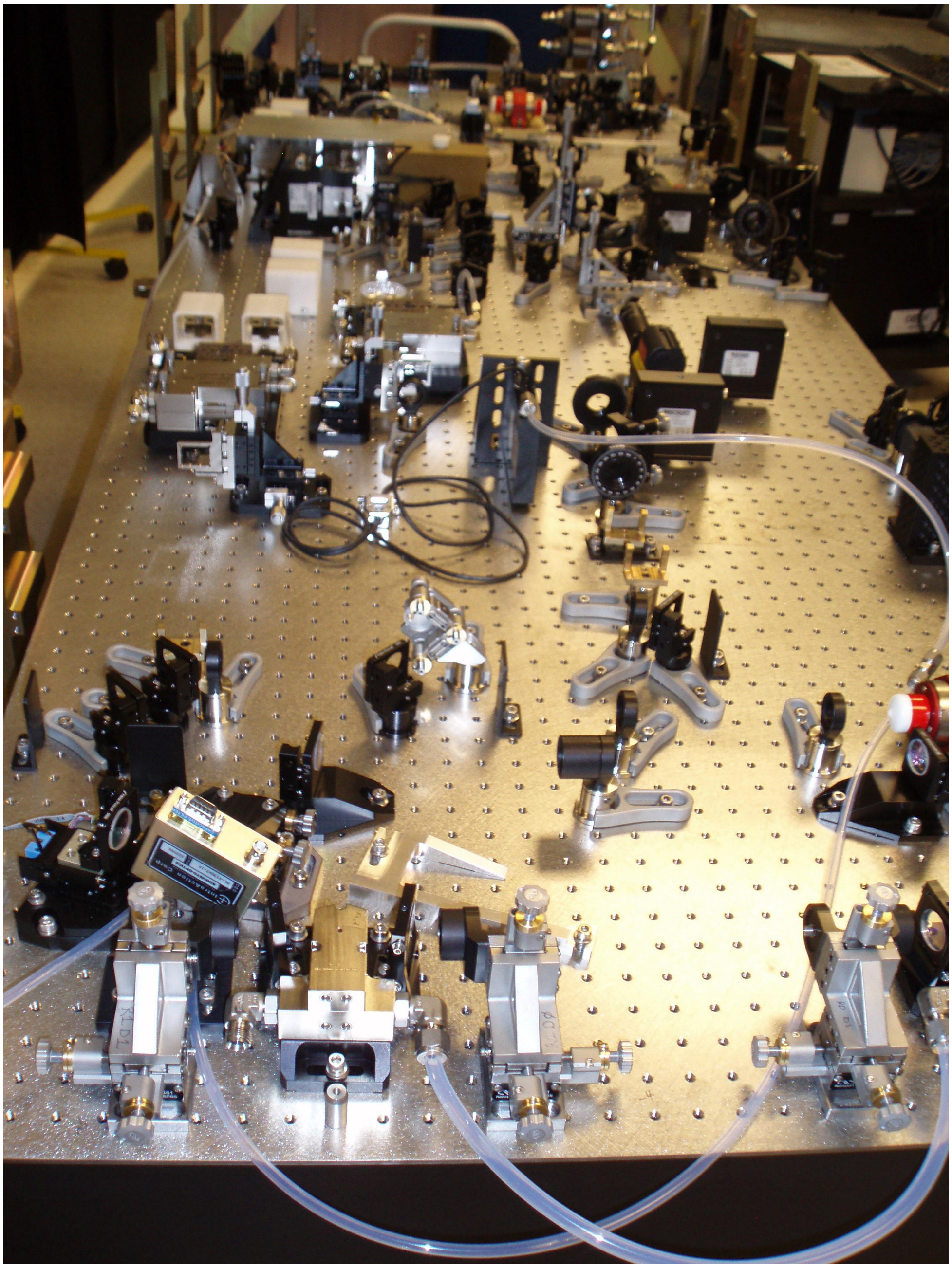
Figure 9: Keck I laser bench with 1319 nm oscillator in foreground

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