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Sodium Beacon Laser System for the Lick Observatory

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ABSTRACT

The installation and performance characteristics of a 20 W sodium beacon laser system for the 3 m Shane telescope at the Lick Observatory are presented.

1. INTRODUCTION

The design and performance predictions of a 20 W laser system for the 3 m Shane telescope at the Lick Observatory were presented in a previous paper.[1] In June of 1995, the laser was propagated from the Shane dome as shown in Figure 1 and the integration, alignment and commissioning process is now underway. In this paper, the hardware is described, installation details discussed, and the laser performance presented.

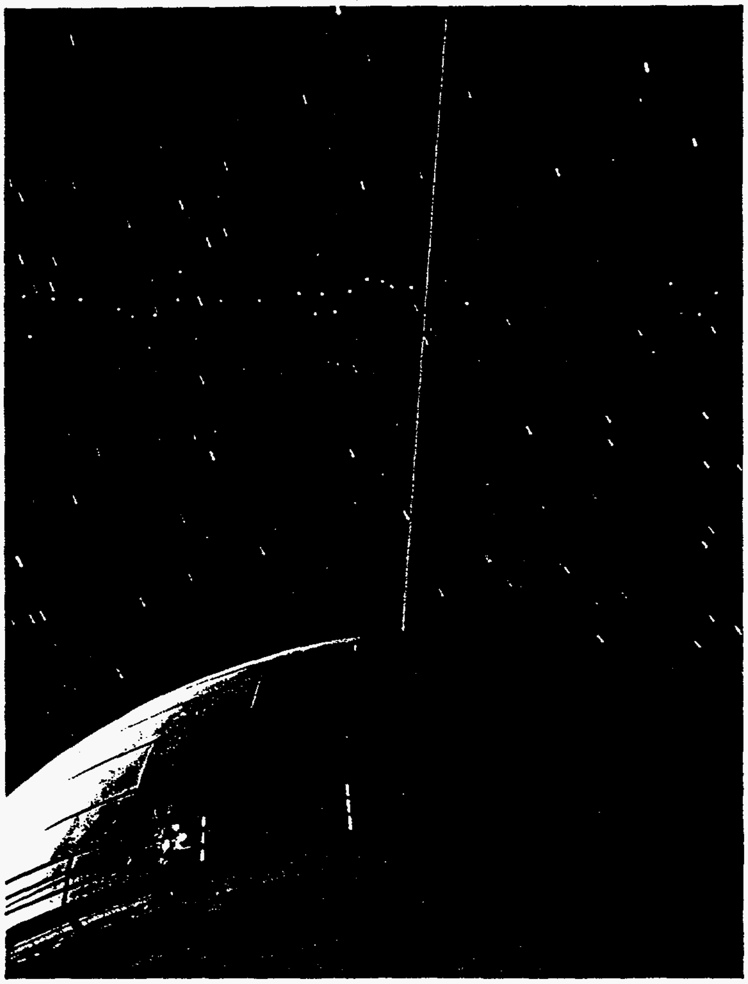

Figure 1. Propagation of the sodium guide star laser from the 3 m Shane dome at the Lick Observatory.

2. GENERAL LAYOUT

A key feature of this laser system is the set of dye laser amplifiers which can be pumped by incoherent light delivered by optical fibers. The pump lasers and wave form generator can therefore be located remotely from the telescope in order to facilitate the removal of waste heat from the dome area as shown in Figure 2. The dye laser amplifiers are then located directly on the telescope, bore sighted to the axis of the telescope and locked down securely thereby eliminating the need for complex beam directors. There is an issue as to whether the laser beam should be transported across the primary mirror and propagated from behind the secondary or simply launched from the side. In numerous calculations and simulations, it has been found that the side or off-axis propagation does introduce some degradation in fitting error of the wave front sensor, but that the error is indeed small, of the order of 0.01 Strehl units, and is not worth the considerable effort to accomplish true coaxial propagation.

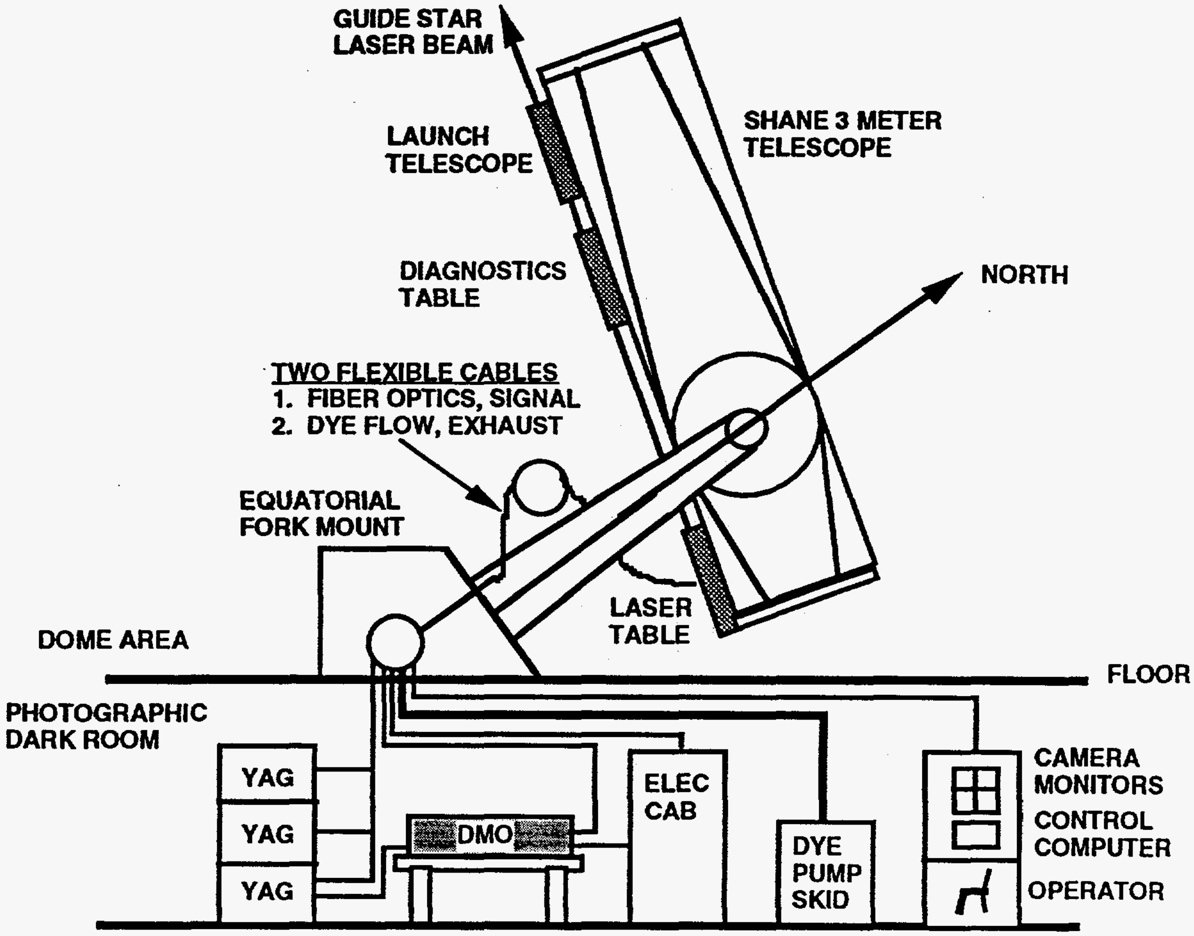

Figure 2. Design for telescope mounted, off axis dye laser amplifiers and remotely located support equipment.

A photograph of the laser installation on the Shane 3 m telescope is shown in Figure 3. The optics table at the base of the telescope contains the dye laser preamplifier and power amplifier while the table at the mid level contains beam control, wave front and power monitoring diagnostics. The launch telescope is the tapered structure at the top which culminates in a 30 cm refractive optic. Optical fibers containing the pump light and dye laser signal are contained in a small, separate umbilical tube while the dye lines are housed in the larger tube. Signal, control and video links are lashed alongside with the entire bundle routed in a cable wrap similar to other cables on the telescope.

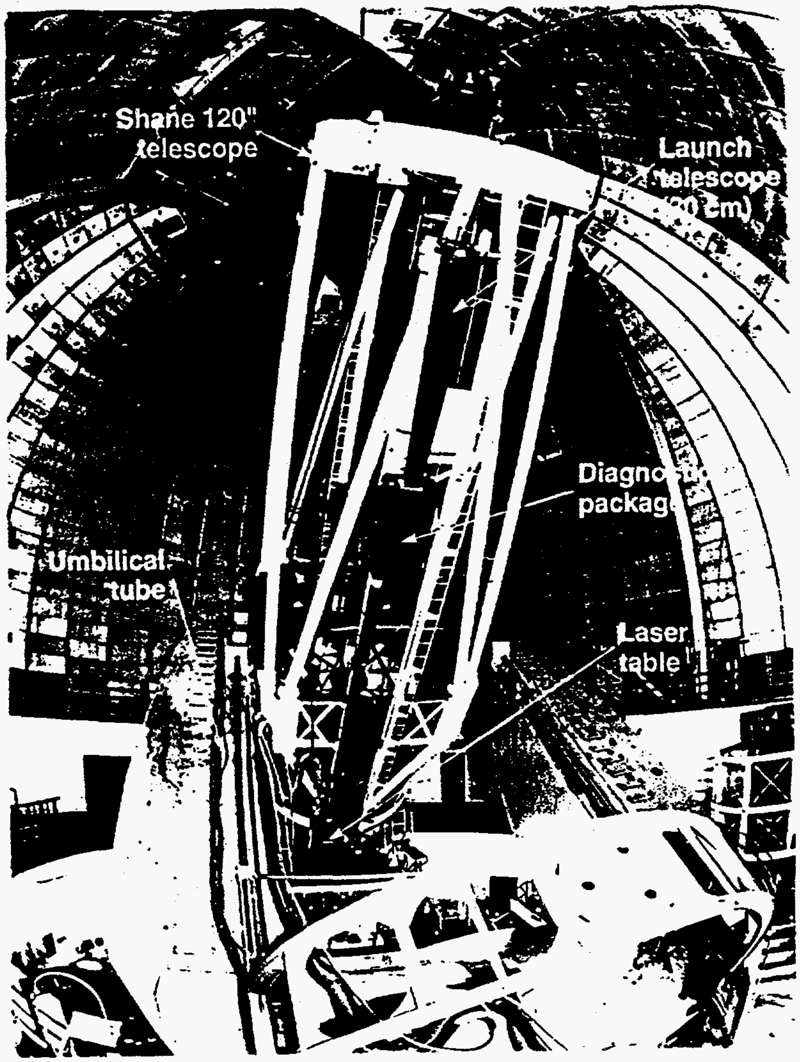

Figure 3. Installation of the 20 W dye laser system on the 3 m telescope.

Prior to installation on the telescope, the entire laser system was assembled and integrated on a (vertical) optics bench as shown in Figure 4. The laser table containing the dye amplifiers was mounted on a rotation table so that its mechanical stability could be verified as a function of (simulated) telescope motions. The six meter distance between the laser and the diagnostics tables was simulated by fold mirrors but the connections between the diagnostic table and launch telescope was full scale. All fiber connections between the pump lasers and wave form generator were full length (60 m) in order to simulate actual performance.

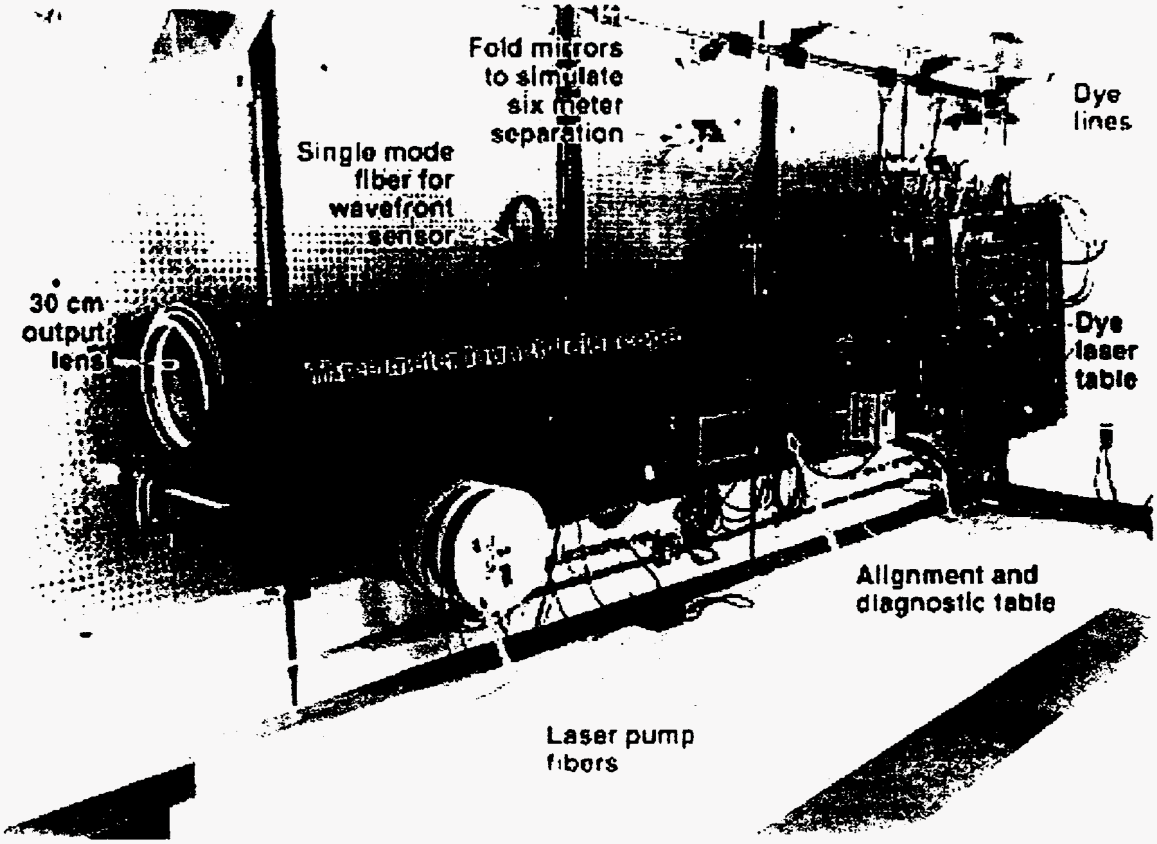

Figure 4. Integration of the guide star laser system prior to installation on the telescope.

The auxiliary support equipment consist of a set of three frequency doubled YAG lasers, wave form generator, two racks of electronics modules, the dye pump system with chiller, the safety/interlock control computer (PLC), and a Macintosh computer work station with LabView software. The wave form generator consists of a Dye Master Oscillator, phase modulator and wavelength control diagnostics and is described in Reference 1. The entire support facility is housed in an air conditioned room measuring 8 feet by 20 feet. Advanced designs would rack mount the YAG lasers, integrate the YAG laser cooling, dye pumps and dye cooling into the observatory facilities, and incorporate the work station into the centralized control room. In this case, the support equipment would fit into a space measuring 6 feet by 10 feet.

3. LASER TABLE

An optical layout of the laser table is shown in Figure 5. A 5 µ single mode fiber from the wave form generator appears in the lower right of the figure followed by a microscope objective to collimate the beam. The power level in the fiber is several milliwatts corresponding to a specific peak power of about 10 MW/cm^2 for these 150 ns, 10 kHz pulses. Beyond this power level, nonlinear effects limit the power handling capability of these fibers. It is to be noted that these nonlinear limits are increased by the modulation format and that narrow bandwidth signals have lower limits. The limited power transmission of single mode fibers is the penalty for the remote location of the wave form generator and a preamplifier on the laser table is needed to restore the dye laser power to the level of the Dye Master Oscillator (DMO) which is the source of the wave form generator. In fact the dye cell of the preamplifier is identically the same as for the DMO only minus the cavity optics and control system.

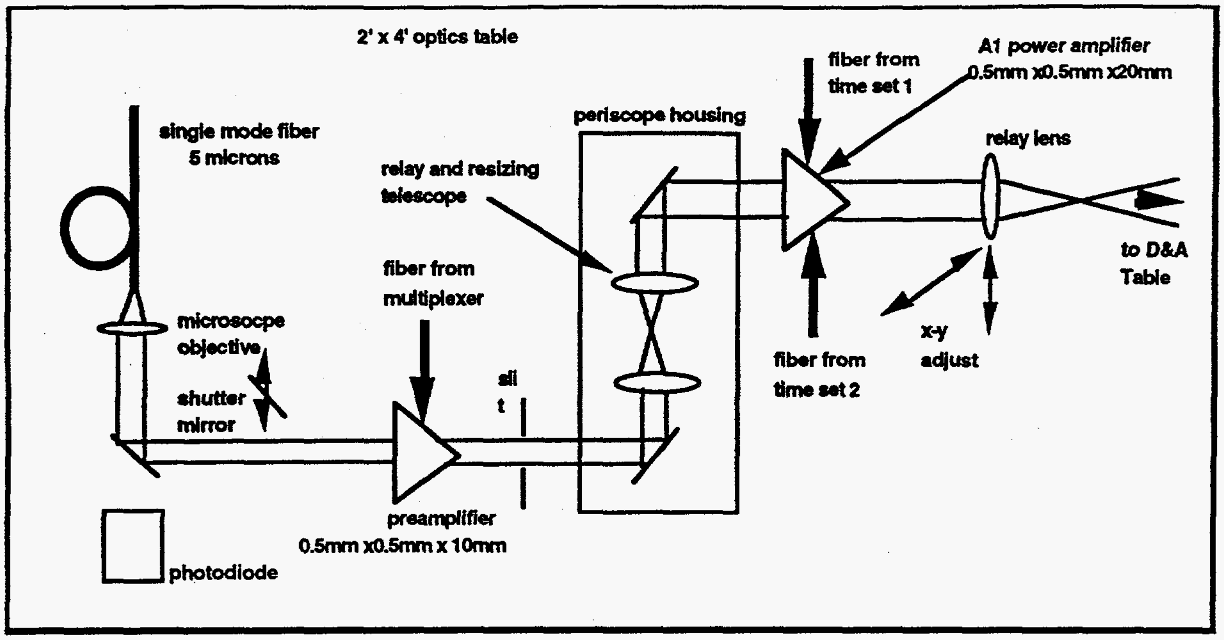

Figure 5. Optical layout of the dye laser table.

The output of the preamplifier at the several hundred milliwatt level is filtered by the (square) pinhole slit which is then resized and (relay) imaged to the center of the power amplifier. Pointing and centering is also accomplished by this Dye Relay Telescope. The power amplifier has a spacing of 0.5 mm and length of 2 cm with a flow of 1.5 gpm corresponding to a dye flow rate of 10^3 cm/s or two dye interchanges per pulse. The input signal to the power amplifier is of the order of 50 mW and the output signal is 22.5 W with a pump power of 150 W (as measured at the YAG laser) as shown in Figure 6. These figures correspond to a overall efficiency of about 15% including a fiber loss of about 25% for the 60 m length and Fresnel loss at the uncoated fiber ends, and an additional 10% loss in the fiber relay telescope which images the fiber ends into the dye cell. Without these loses, the intrinsic dye conversion efficiency corresponds to 22%.

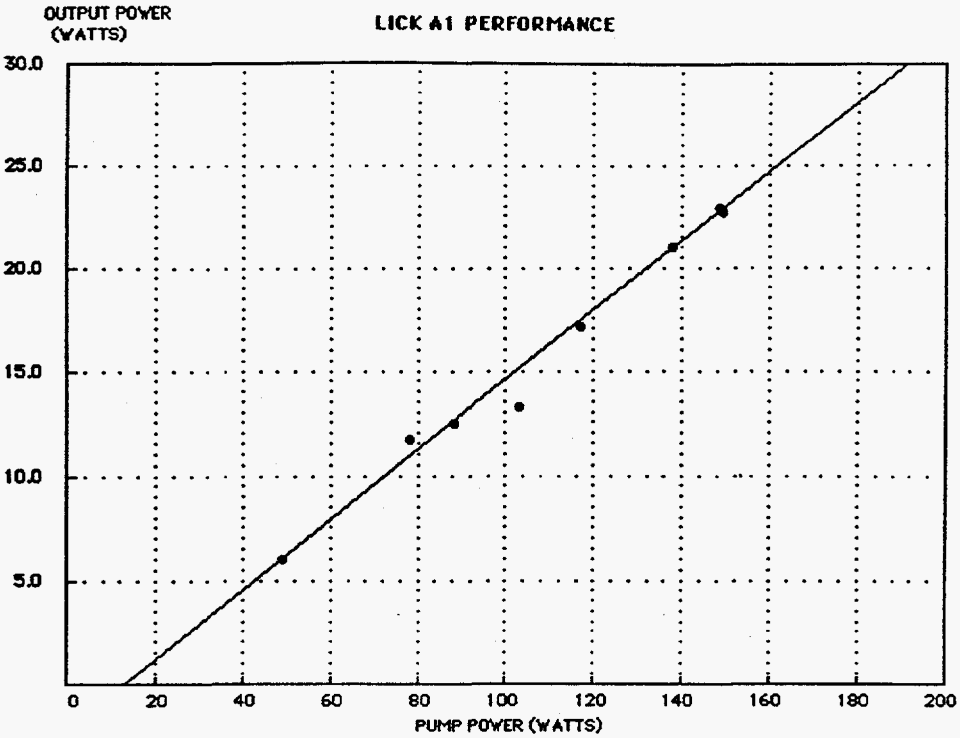

Figure 6. Performance characteristics of the dye laser power amplifier.

Scaling this technology to higher power levels such as would be required for visible wavelength astronomy, would require a second power amplifier. There is already sufficient room on the dye laser table for a second amplifier as is evident from the photograph of Figure 7. This second power amplifier would be identical to the first but with a larger gap of 1 mm. The efficiency of this second amplifier should be higher than the first. The gain of the first amplifier is approximately 20 W/50 mW = 400 which put this device in the small signal, low efficiency region of operation. The second amplifier would operate in the saturated, high efficiency region with gains of 5-10 and should have an efficiency >25%. Under these conditions the number of YAG pump lasers required to reach the 100-200 W level is in the range of 5-10.

4. DIAGNOSTICS AND ALIGNMENT TABLE

An optical layout of the Diagnostics & Alignment (D&A) table is shown in Figure 8. The first optic on the table is a commercial, high speed tilt stage (Physic Instrumente) which removes all tilts of the laser beam including those induced by the laser, optics, atmosphere, etc. These tilts are sensed by the wave front sensor in the Adaptive Optics system which views the mesospheric guide star and are transmitted to the tilt stage forming a closed loop control system. After a turning mirror, the beam is passed through a radar controlled safety shutter which is part of the aircraft avoidance system. In the closed mode, the beam is dumped into a power meter.

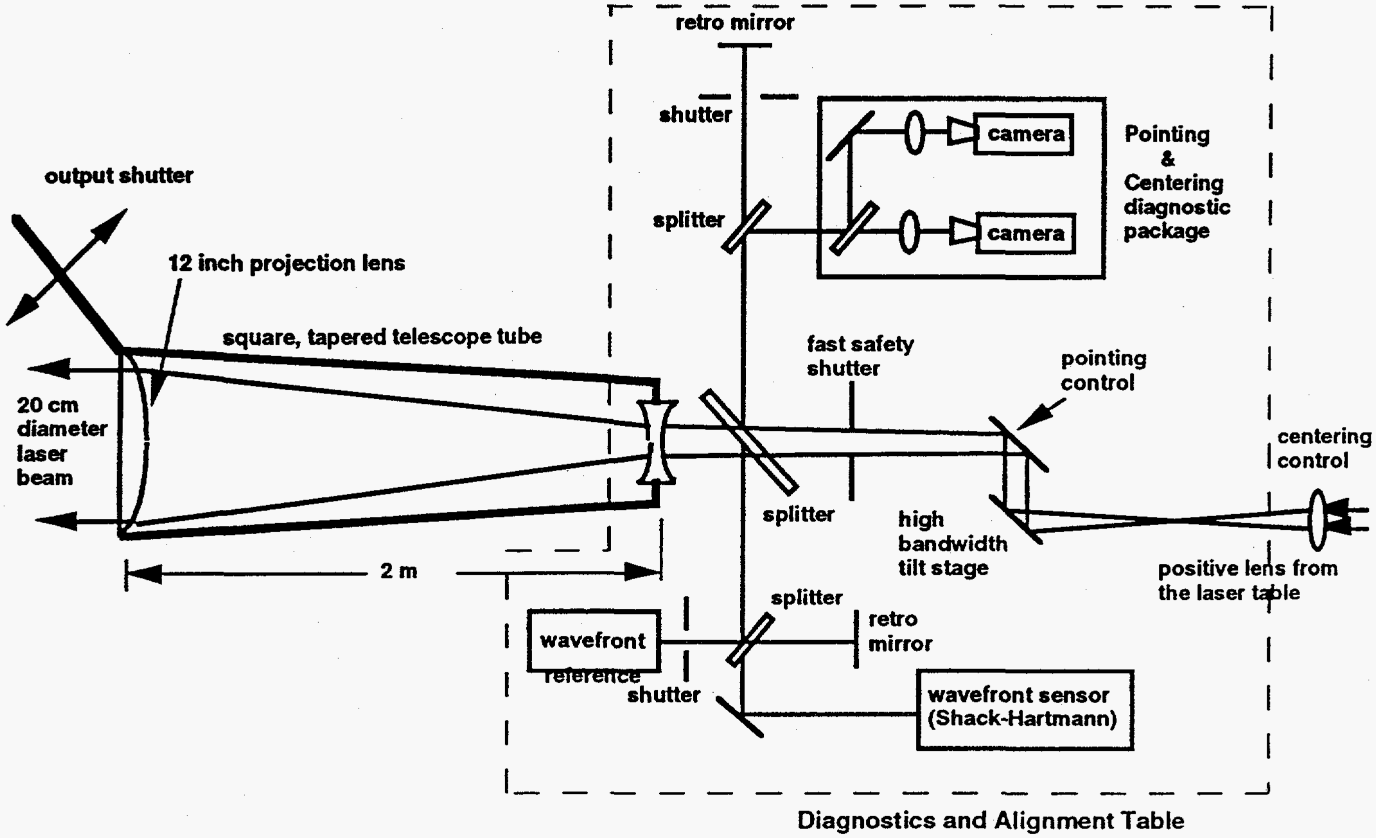

Figure 8. Optical layout of the D&A table

After the safety shutter but before the primary lens of the launch telescope, a beam splitter samples the laser and inserts a portion of the beam into a P&C diagnostic package. The cross coupled output of this diagnostic package controls the "optics-couple" formed by the turning mirror and relay lens on the laser table to maintain pointing and centering to a fixed position, usually determined by alignment of the guide star on the science objects in the Adaptive Optic system.

The rest of the sampled beam is retro reflected into the on-board Hartmann wave front sensor which is calibrated by the wave front reference. This wave front reference is generated by a single mode HeNe laser operating at 594 nm and located near the pump lasers. The output of this laser is transmitted to the D&A table via another single mode fiber where it is expanded and collimated in an Invar mounted optics system. Since the laser beam is not collimated at this point, the beam will have several waves of divergence from the rely lens. This divergence is "subtracted" by comparing the forward going laser beam with a retro reflection from generated by the flat surface of the 30 cm lens which forms the primary of the launch telescope. In practice, the wave front sensor operates by first taking an exposure of the wave front reference, followed by a second exposure of the outgoing laser beam and finally, an exposure of the retro wave from the launch telescope. The three exposures are controlled by shutters in the optics system and require about 3 seconds for a full set. An example of the wave front leaving the dome as measured by these three exposures is shown in Figure 9. The rms wave front error is about 1/7 waves which will result in a Strehl ratio in the mesosphere of about 45% according to the Mareshal approximation, $\exp(-\sigma^2)$ where $\sigma = (1/7)2\pi$.

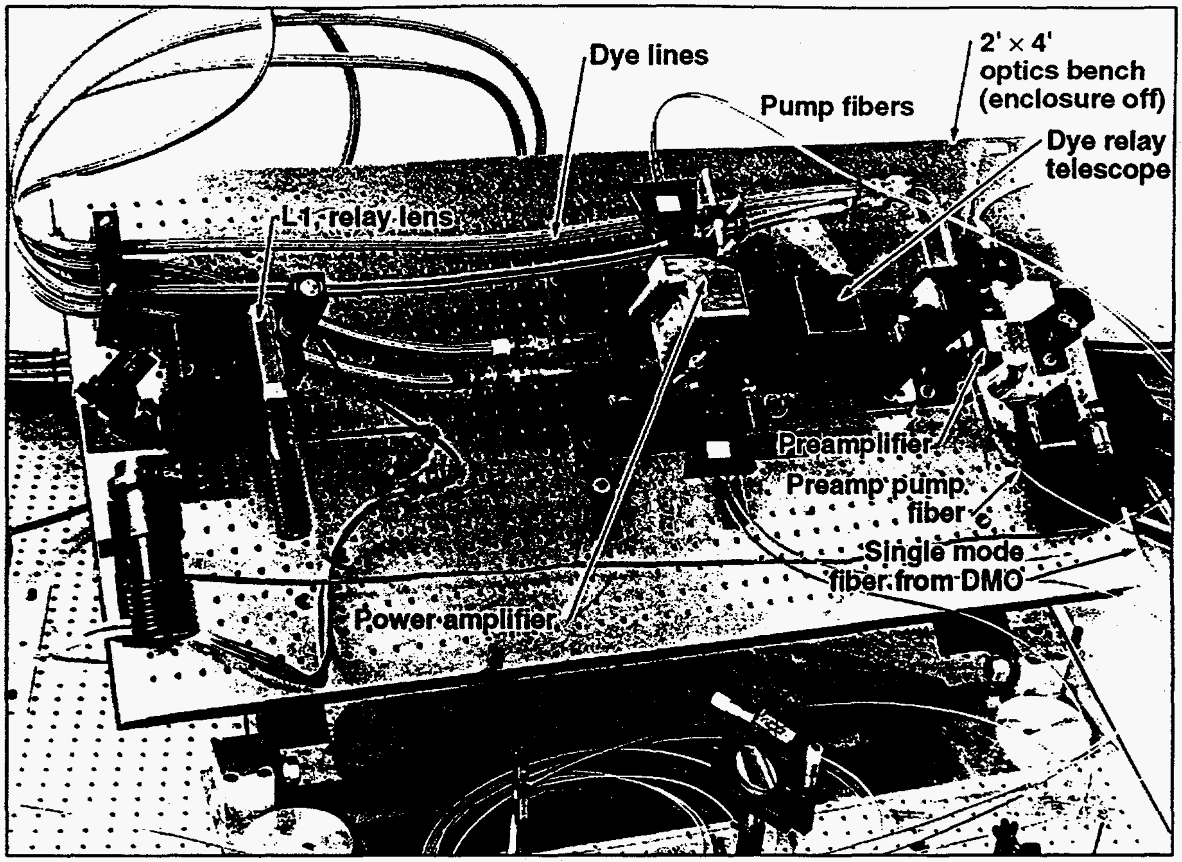

Figure 7. Photograph of the dye laser table with the cover removed.

The final lens on the laser table is used to relay the image of the center of the power amplifier to the exit of the launch telescope thereby eliminating diffraction effects which would otherwise increase the spot diameter in the mesosphere. Alternatively the size of the output optic could be increased to capture the diffraction spreading but only at a significant cost increase. The minimum separation distance between the power amplifier and the relay lens is about 40 cm dictated by diffraction effects with increase the axial intensity in the near field. The relay lens has motion capability in the plane transverse to its axis as part of the Pointing & Centering (P&C) loop.

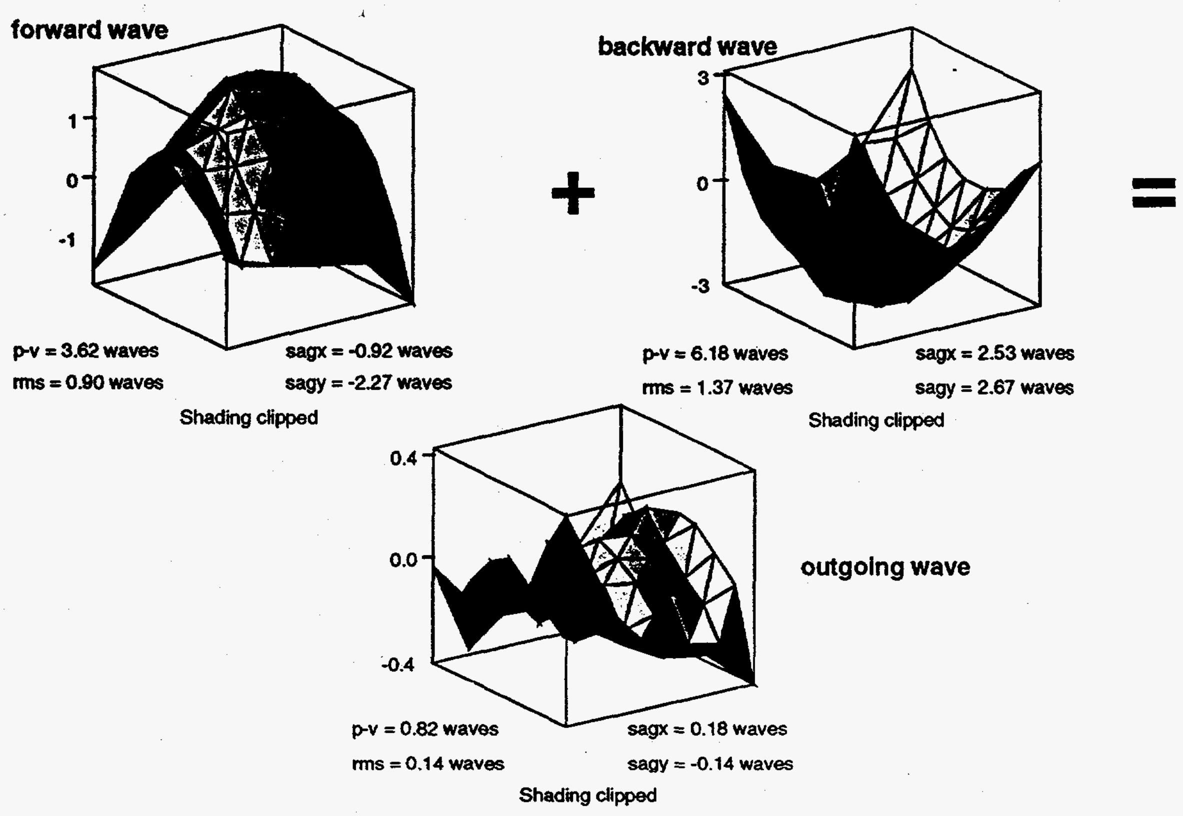

Figure 9. Wave front of the laser beam leaving the launch telescope as measured by the on-board Hartmann sensor.

The purpose of all these diagnostics is to ensure the quality and stability of the laser beam before it leaves the dome. This philosophy is in contrast to simpler schemes which use the spot in the mesosphere as the primary diagnostic. It has been our experience in both laser guide star experiments as well as complex integration demonstrations involving laser systems and adaptive optics, that it is essential to have a full suite of diagnostics on-board the laser system in order to rapidly acquire the laser beam and reduce down time when difficulties do occur. This is especially important in the astronomical application where telescope time is quite valuable. A photograph of the D&A table is shown in Figure 10 where the main beam path has been indicated by white streak.

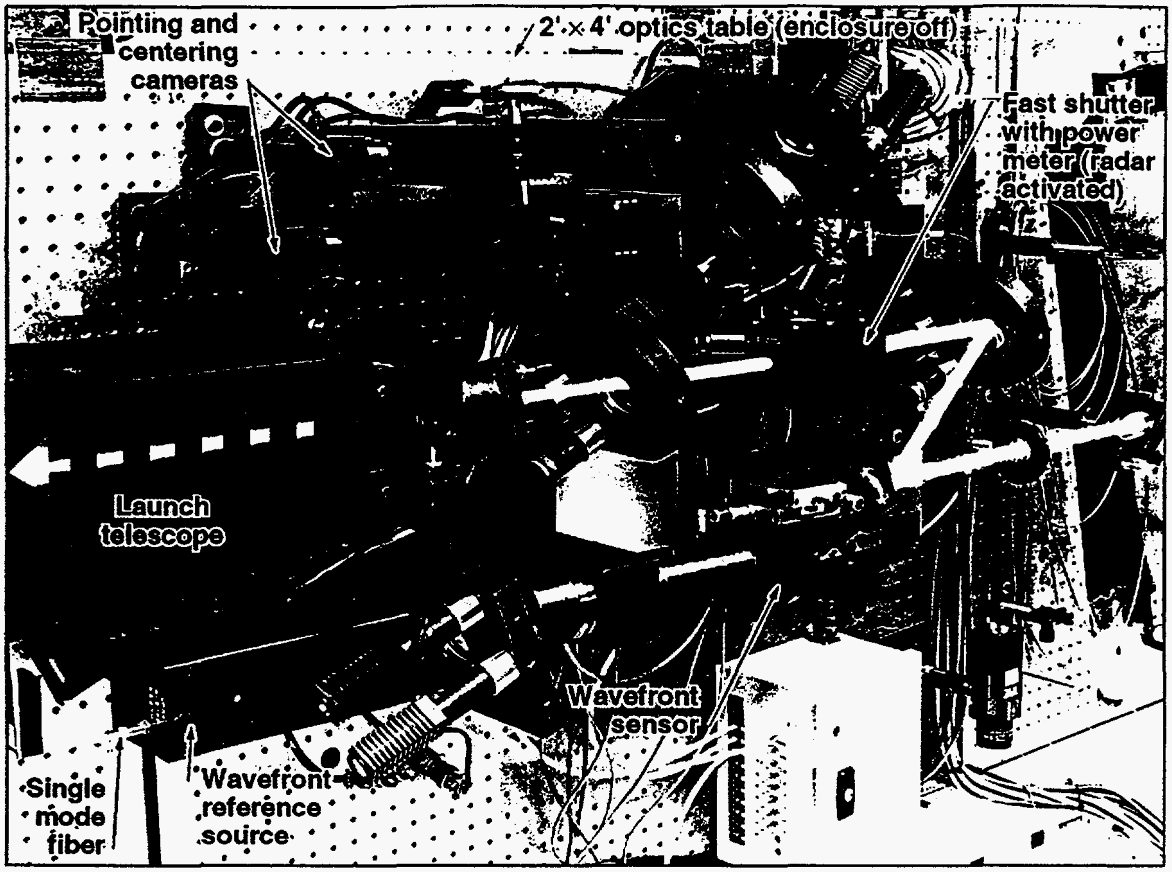

Figure 10. Photograph of the Diagnostics and Alignment table with the main beam path indicated in white.

5. SUMMARY

A 20 W sodium guide star laser has been installed on the 3 m Shane telescope at the Lick Observatory. The use of dye amplifiers and optical fibers have allowed the frequency doubled YAG pump lasers and the dye laser wave form generator to be remotely located leaving the dye amplifiers to be strapped directly to the side of the telescope. With the measured wave front quality of 1/7 wave (rms) and the pulse duration of 100 ns (FWHM), the peak power intensity in the ≈ 60 cm spot diameter will be a few watts per square centimeter, which is below the saturation flux of ≈ 5 W/cm^2. The laser has been operated at the 20 W level for several hours at time with amplitude stability of ±5% with fine adjustments on a 10-20 minute basis. Closed loop control systems developed at LLNL could be applied to the wave form generator which would extend the adjustment period to the level of an hour or more.

Unfortunately, the combination of poor weather and limited access to the telescope have delayed the final bore sight alignment of the laser launch telescope to the 3 m telescope. At this point, we have not been able to acquire the laser guide star in the acquisition camera of the 3 m telescope in order to measure its diameter or return signal. We expect to complete this task in the coming months. An adaptive optics package consisting of a Hartmann wave front sensor, continuous face sheet deformable mirror, tilt sensor and mirror stage, and the Lick Infrared Camera (LIRC II)[2] has been tested on the 3 m telescope using natural guide stars. The system has produced diffraction limited images at 2.2 μ and has improved the seeing from the arcsecond level to <1/4 arcsec. The laser system will be integrated with this adaptive optics package in the coming months for the first sodium-layer guide star, closed loop adaptive optics system.

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6. REFERENCES

1. H. W. Friedman, et al., SPIE Paper 2201-36 Adaptive Optics in Astronomy (1994)/352

2. S. Olivier et al., SPIE Paper 2534-03, Adaptive Optical Systems and Applications (1995)