The ALFA Dye Laser System

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Abstract

The ALFA adaptive optics system at Calar Alto Observatory uses a continuous-wave dye laser (Coherent model 899-21) pumped by an argon ion laser (Coherent model Innova 400) to create a sodium guide star. The pump laser delivers 25 W of multiline output power routinely. We describe the optimization of the dye laser for operation at this high pump level. Up to 5.5 W of single-line output power have been achieved in the laboratory; at the telescope the dye laser is routinely operated at 3.75 W of single-line power. The laser is stabilized to the sodium D_2 line at 589 nm with a sodium vapor cell located on the laser bench. In normal operation the laser frequency is locked to the Lamb dip in the sodium cell; for diagnostic purposes it is also possible to scan or modulate the laser frequency under computer control. The laser system is located in the coudé room of the Calar Alto 3.5 m telescope. The laser beam is transmitted backwards through the coudé train and expanded with a 50 cm Cassegrain telescope attached to the mirror cell of the 3.5 m telescope. A CCD camera mounted behind the telescope secondary triggers a fast shutter when aircraft are detected to avoid dazzling the pilots.

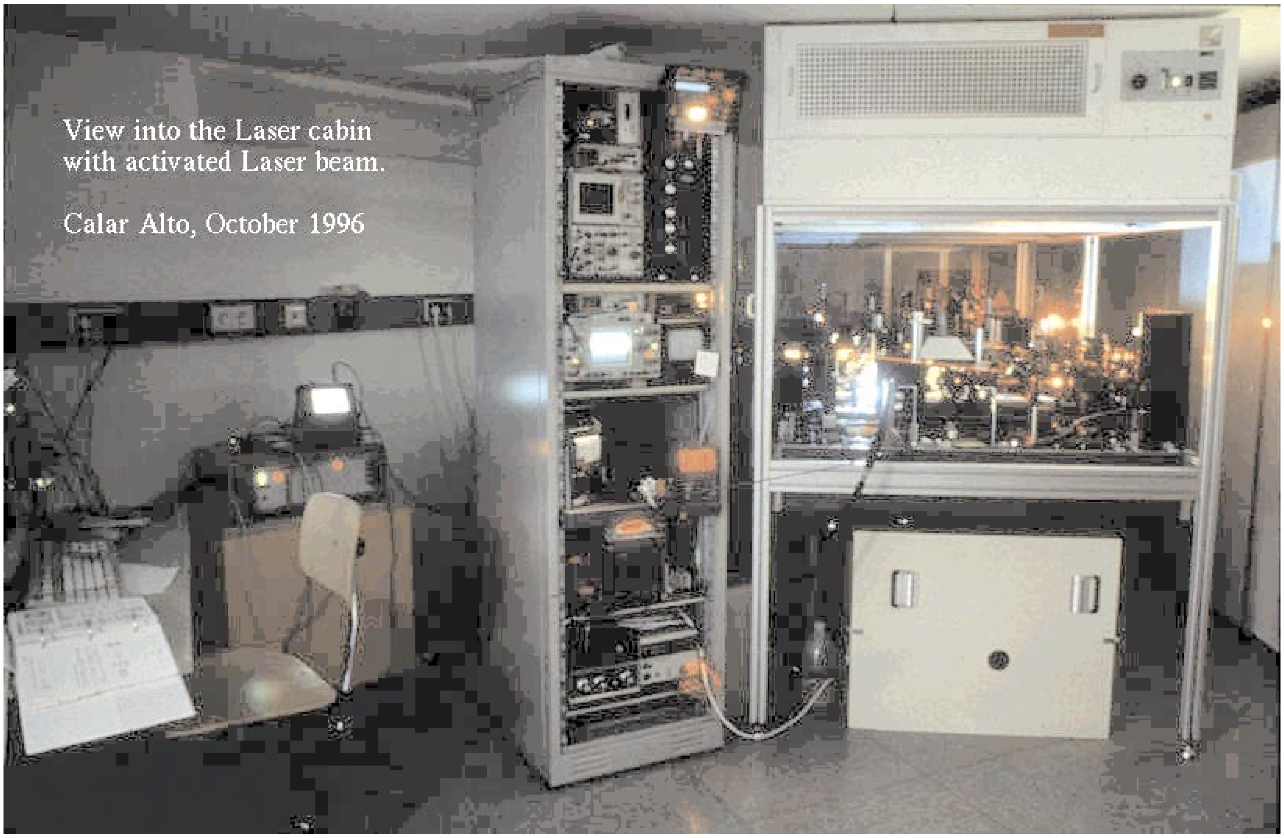
1. Introduction

Planning for ALFA (Adaptive optics with Laser guide star For Astronomy) started in 1994. At that time a collaboration between the Max-Planck-Institutes for Astronomy (Heidelberg) and Extraterrestrial Physics (Garching) was formed to provide the German-Spanish Center for Astronomy on Calar Alto with an adaptive optics system, including a sodium laser guide star. Several laser technologies were considered: sum-frequency Nd:YAG lasers, pulsed dye lasers pumped by copper vapor or Nd:YAG lasers, and continuous-wave dye lasers with argon ion lasers as pump sources. This last technology was chosen mainly for cost reasons, and because it was the only choice of a system that needed only minor modifications of commercially available lasers. It seemed possible to optimize a cw dye laser for operation at high pump power (25 to 30 W), and to obtain at least 3 W of single-line output power with good beam quality from such a system. Here we give an overview of ALFA's laser system with emphasis on the dye laser; previous accounts of the ALFA laser and beam projection systems have been given by Quirrenbach (1996) and Quirrenbach et al. (1997).

2. Optimization of the Dye Laser for Operation at High Pump Power

The heart of the ALFA laser system consists of a modified commercial dye ring laser (Coherent model 899-21), pumped by the multiline output of a 25 W argon ion laser (Coherent model Innova 400).

Unidirectional ring lasers with traveling wave-fields have advantages over bidirectional or standing-wave dye lasers because of their more efficient use of the available gain in the active medium and better spectral characteristics. In the active medium of linear dye lasers there are regions of unsaturated gain at the nodes of the standing wave. Such "holes" limit the pump power and therefore the output power to relatively small values before secondary cavity modes appear. Suppression of such effects in standing-wave dye lasers requires increasing the finesse of the etalons used for the frequency selection. But this produces more insertion loss and less conversion efficiency. In ring dye lasers, however, the traveling wave fills up the active medium uniformly, increasing the conversion efficiency.



The hierarchy of oscillation frequency selection in the dye laser starts with a three-plate birefringent filter. This filter is followed by two electronically controlled etalons with progressively higher resolution. For frequency fine tuning the cavity length of the ring laser can be continuously changed by rotating a single galvo-driven Brewster plate.

With passive frequency stabilization the effective laser linewidth is typically ± 20 MHz. To reduce the laser-linewidth further (about 1 MHz rms) the cavity length of the dye laser can be actively stabilized, with a frequency error signal sent to the galvo-driven Brewster-plate and to a piezo-mounted cavity mirror. The error signal is provided by an external reference cavity, which is a temperature- and pressure-stabilized, scanning, confocal Fabry-Perot interferometer. For absolute wavelength tuning and long-term frequency stabilization the reference cavity is locked to the Lamb dip in the saturated fluorescence signal of the D_2 line from a temperature-controlled sodium cell, into which a fraction of the dye laser light is sent. For diagnostic purposes (e.g., for acquisition of the mesospheric sodium spot with a telescope guide camera) it is sometimes useful to "blink" the sodium return signal without changing the lower-atmosphere ("Rayleigh") signal. This can easily be achieved by modulating the dye laser frequency with a triangle wave under computer control.

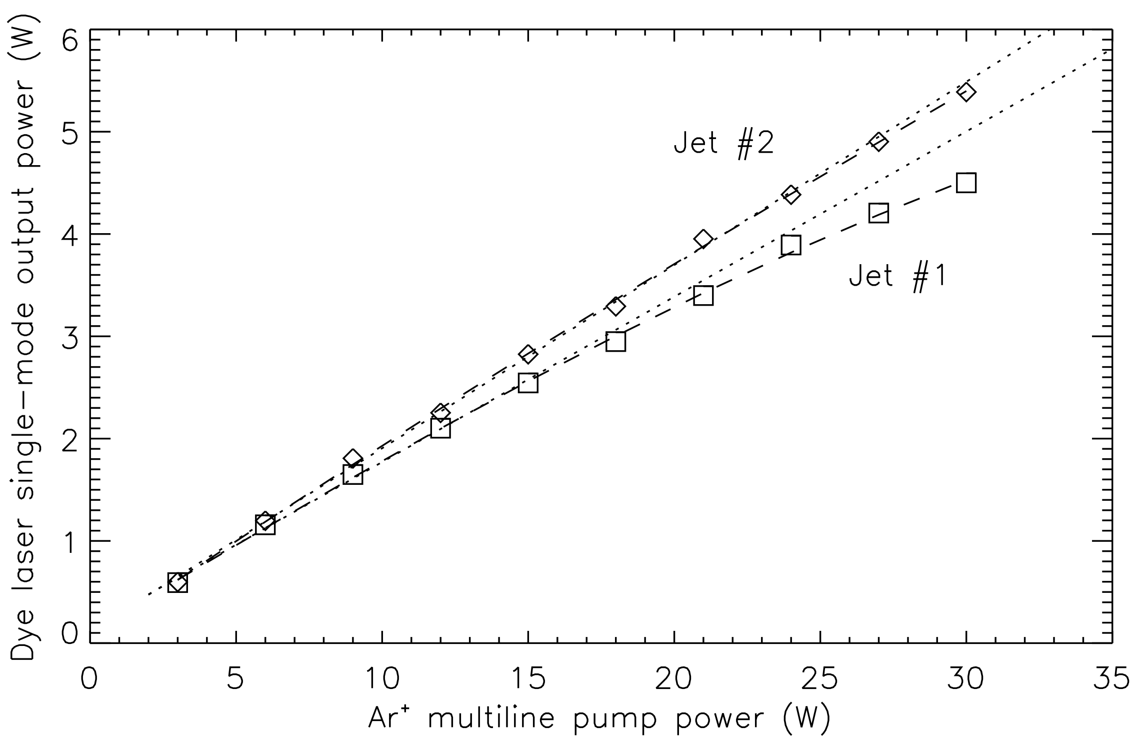
To achieve optimum performance of the AO LGS system, the dye laser has to provide high power with Gaussian mode structure and a narrowband spectrum at the same time. We have optimized the noncollinear pumping geometry, the cavity output transmission and the active laser medium itself to meet these requirements.

Because of the heat produced in the dye jet by that fraction of the energy in the focused pump light which is not reradiated as fluorescence, and because of triplet state trapping, it is necessary to have the dye molecules traverse the pump spot very rapidly. This is achieved by a high-pressure dye circulation system, made from material compatible with Rhodamine 6G, which cools, filters and pumps the dye solution. Attention was paid to effective damping of vibrations.

The jet-shaping nozzle is constructed from two stainless steel plates with highly polished dye contact surfaces and with the jet thickness and height controlled by precision spacers. By analyzing both the jet-thickness fluctuations with a Mach-Zehnder interferometer and directly by measuring laser power, mode quality and effective linewidth, the optimum flow velocity at a given viscosity of the dye solvent and jet thickness was determined. In order to avoid concentration quenching the optimum jet thickness at optimum flow velocity was found to be around 0.3 mm with the dye absorption set to about 80 % and an optimum jet height of 6 mm.

The dye laser single-frequency output power in the case of a glycol-based dye solution was found to be limited to about 4.5 W (30 W pump) if a near diffraction-limited mode structure is required. Even higher output power is probably possible with the use of a chemical triplet quencher.

The heating of the dye at the pump spot causes thermal (and thus optical) distortion of the jet which can break up the desired Gaussian mode of the laser output. With Rh6G dissolved in water, which has a high thermal conductivity and a nearly constant index of refraction up to temperatures of about 50° C, negligible thermal distortion of the optical quality of the dye jet occurs up to pump powers of 30 W. To form a stable jet of high optical quality, the viscosity of the water is raised by adding detergent to the solvent. With this solution a single-mode output power of up to 5.5 W at 589 nm could be achieved in the laboratory. For regular operation at the telescope, however, we currently use a glycol-based dye solution because it requires less maintenance. 3.75 W of single-line output power are routinely obtained without extensive optimization.



3. Beam Projection and Aircraft Detection

The ALFA laser system is located in the coudé room of the 3.5 m telescope. The laser beam is pre-expanded to a diameter of 2 cm on the laser table and projected back through the coudé

Table 1: Optimized parameters of the dye jet for two different dye solutions.

	Jet ♯1	Jet ♯2
Solvent	ethylene glycol	75 % water + 20 % lauryl amine + 5 % polyvinyl glycol
Temperature	23° C	8° C
Jet Thickness / Height	0.3 / 6 mm	0.3 / 6 mm
Flow Velocity	22 m / s	14 m / s
Rh6G Absorption	75%	80%
Pump Focus Spot Ø	25 μm	20 μm

train. On the declination axis, however, the beam is picked off by a small mirror; from there it is sent around the mirror cell to a 50 cm Cassegrain telescope, which expands the beam to its final diameter. The beam position is measured at several places in the beam train with position-sensitive devices and corrected with motorized mirrors. The secondary mirror of the beam expansion telescope can be controlled in all three axes to allow for focusing into the mesospheric sodium layer and fast beam steering on the sky. The ALFA beam projection system has been described in more detail by Quirrenbach et al. (1997).

To protect pilots of passing aircraft from being dazzled by the laser beam, an aircraft detection system has been installed and will be integrated into the LGS control software in the fall of 1997. This system automatically shuts down the laser whenever an aircraft enters an area close to the emitted laser beam. ALIENS (Aircraft Light Imaging Emergency Notification System) has been developed by AOA Inc. (Boston, MA) for this purpose. Its algorithms are based on the analysis of visible images of the sky to detect aircraft lights. These images are acquired by two CCD cameras, one with a wide FOV of 90° to give an early warning of approaching aircraft, and another with a narrow FOV of 20°, which automatically closes the shutter of the laser whenever an aircraft is detected. The narrow-FOV camera has been mounted behind the secondary mirror of the telescope and its FOV has been selected to cover an area as large as possible, looking through the open slit of the dome.

The algorithm compares successive frames from one of the CCDs and detects any changes that exceed a given threshold level. However, a number of refinements have been made to this basic scheme, to account for operation of the LGS system without the telescope being in tracking mode, to prevent false alarms from scintillation of stars, and to blank areas with telescope or dome structures in them, which, when illuminated by stray light could also trigger false alarms. A UNIX workstation is used to operate this system and to carry out the image analysis.

4. References

Quirrenbach, A. (1996). *Adaptive optics at MPE: astronomical results and future plans.* In *Adaptive optics, 1996 Technical digest series Vol. 13.* Optical Society of America, p. 166-167

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