ARGOS : A Laser Star Constellation For The LBT

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ABSTRACT

ARGOS is an innovative multi-star adaptive optics system being built for use with LUCIFER on the Large Binocular Telescope (LBT). LUCIFER is a wide field imager and multi-object spectrograph. Using a constellation of laser guide stars permits PSF correction over a wide field in exchange for a relatively small sacrifice in achievable correction. The laser constellation consists of three stars per each of the two eyes of the LBT. The stars are nominally positioned on a circle 2' in radius, but each star can be moved by upto 0.5' in any direction. Nd:YAG (SHG) lasers from InnoLas Laser GmbH are used to create the green (532nm) laser stars, and have an output above 18 W each at the planned pulsing frequency of 10kHz. The lasers are launched using a 40cm telescope and focused at a height of 12 km. The laser system is designed to be optically simple yet configurable. It also provisions for a central sodium laser to be installed later. We detail the characteristics of the laser system and the current state of its development.

Keywords: ARGOS, LBT, LUCIFER, Lasers, Adaptic Optics, Nd:YAG

1. INTRODUCTION

To utilize the full benefits of a large and unique telescope like the Large Binocular Telescope (LBT), an adaptive optics (AO) system is essential. A Natural Guide Star (NGS) based First Light Adaptive Optics (FLAO) system is the natural first step in that direction. Natural or Laser Guide Star (LGS) systems used at most large telescopes operate with a single guide star can provide diffraction-limited resolution, but such performance is restricted to a very narrow field around the guide star.

To overcome this limitation at LBT, especially for the LUCIFER wide field imager and multi-object spectrograph, a multiple Laser Guide Star (LGS) system was proposed.¹ The performance required of this system is not a diffraction-limited performance, but rather an improvement of spatial resolution with LUCIFER by a factor of 2-3 over a wide range of seeing conditions. To achieve the AO capability over a wide field of view (FOV), multiple guide stars will be used. The unique binocular nature of LBT requires a seperate AO setup for each of its two sub-telescopes (or eyes). A further utility envisioned for this system is, with upgrades, to provide diffraction-limited performance for LUCIFER and to support the operation of the LBT Interferometer (LBTI).

2. OPERATIONAL REQUIREMENTS

A schematic of the ARGOS system is shown in Figure 1. The system along the optical path begins in the laser system that provides correctly configured laser beams to be relayed by the launch telescope. The pulsed are synchronized, and the rayleigh scattered stars are imaged by the primary telescope. The FLAO system that uses a natural star provides the tip-tilt correction for the system. The light from the laser stars is picked up by a dichroic mirror in from of the LUCIFER camera, and passes through a timed electro-optic Pockels-cell gating system to a wavefront sensing system.² The images are analyzed by the ARGOS Basic Computing Unit (BCU), and the corrections are parcelled out to the correction systems. The fast tip-tilt of the laser stars (after the FLAO correction) is performed by the piezo-electric tip-tilt pupil mirror in the laser system (see Section 4). Slower variations between the laser stars are corrected by the two-mirror tip-tilt system of the individual lasers. Longer time-scale changes caused by flexture in the telescope system or larger accumulated offsets are corrected by the large launch mirror ilocated behind the telescope secondary mirror.

The full requirements on the ARGOS system are described in Rabien et. al (2008)¹ and elsewhere in these proceedings. A brief listing of the requirements includes an image enhancement by a factor of 2 or more over 75% of nights the ARGOS

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Adaptive Optics Systems II, edited by Brent L. Ellerbroek, Michael Hart, Norbert Hubin, Peter L. Wizinowich, Proc. of SPIE Vol. 7736, 77364D · © 2010 SPIE · CCC code: 0277-786X/10/\$18 · doi: 10.1117/12.862448



Figure 1. A schematic of the ARGOS system.

system is used, with a increase in target acquisition time of no more than 10 minutes over the NGS basd FLAO system, and an increase of no more than 30 seconds in observing time over the FLAO system. A listing of the operational requirements on the laser system of ARGOS is given in Figure 2. Additional mechanical/electrical/thermal requirements are imposed by the telescope and observatory systems.

The laser stars on sky are required to be linearly polarized with the polarization axis aligned with the nasmyth axis of the LUCIFER dewar to maximize the efficincy of the dichroic pick-off mirror as well as the Pockels cell based electro-

Number of laser beacons per side	3	
GLAO constellation radius	2	arcmin
Constellation radius range	1.5-2.5	arcmin
Beacon positioning range around nominal for flexure compensation (on sky)	1	arcmin
Gated laser beacon height	12±1	km
Laser wavelength	532	nm
Laser average power per beacon at 10kHz	>18	w
Laser normal operation repetition rate	10	kHz
Laser adjustable repetition rate	1-20	kHz
Laser pulse output external triggerable		
Laser pulse length	<40	ns
Laser pulse energy fluctuations	<5%	rms
Laser beam roundness	>80% circular	
Laser beam polarization at head exit	>100:1	
Laser beam polarization at laser system exit	Adjusted such that the polarization arrives linear and matched to the acceptance of the WFS within ±5°	
Laser beam field pointing accuracy at laser system exit	5	arcsec
Laser beam pointing direction	External controllable	
Laser beam position accuracy at pupil mirror	1	mm
Laser pulse output to trigger input timing jitter	<9	ns rms
Laser system wavefront deformation from head to after pupil mirror	≪V/10 over beam diameter	
Laser system transmission from head exit to after pupil mirror	>95%	

Figure 2. The operational requirements on the laser system part of ARGOS.

optic gating system. The locations of the stars on the sky with respect to the telescope axis and the orientation of their polarization is shown in Figure 3. The locations of the laser systems and the launch telescopes are also shown. The laser constellation consists of three stars per each of the two eyes of the LBT. The stars are nominally positioned on a circle 2' in radius, but each star can be moved by upto 0.5' in any direction.



Figure 3. The positions and polarization axes of the laser guide stars on the sky.

3. LASERS

The lasers for ARGOS were selected after an evaluation of lasers from multiple vendors. The JDSU Q-series, Photonics Industries DS20 and InnoLas Nanio-18 lasers were considered and bids requested. In the end, the Nanio-18 lasers were chosen, and were delivered to MPE in late 2009. Figure 4 shows three of the lasers being operate by a single cooling system. While the lasers remain at MPE through the assembly and testing period for the system, they are being regularly tested to ascertain their long-term stability and performance.



Figure 4. The lasers from InnoLas laser GmbH undergoing acceptance tests. All the lasers exceed the power requirement at 10 kHz.

4. OPTICAL DESIGN

Setup of the laser system on one eye of the telescope is a mirror image of the other, and the descriptions here apply to both copies. The laser beams as they exit the laserheads are 1.4-1.6 mm in $1/e^2$ diameter, and are expanded by $4 \times$ to a $1/e^2$ diameter of 5.7 mm to provide more than 98% of the laser power in a beam 8 mm in diameter. The expanded laser beams are expected to reach the pupil mirror in a circular pattern with an angle of incidence of 100/, which the 1:50 expanding laser launch telescope will project on the sky as a three star circular pattern with a 2/ radius. The laser system also plans ahead for an additional fourth laser at the center of the circle formed by the three lasers. The upgrade is currently expected to use a sodium laser at that location to create a hybrid AO system. There is a further requirement that the beams, after they leave the launch system, retain a near-complete linear polarization oriented in a direction as represented in Figure 3. This is so that the the scattered laser light arriving at the dichroic in front of Lucifer allow for best coating efficiency.

The polarization planes on sky are therefore aligned with the Lucifer plane. To rotate the polarized laser output into the right direction, a Berek's Compensator is considered the ideal solution. Due to the unique optical path of each of the three laser beams within the laser system, a different configuration is needed for each of the beams, and the design is to place and individually calibrate a Berek's Compensator at the exit of each pre-expander. The accuracy requirement for this orientation is about 5°, which limits the flux loss on the imaging side of the system due to polarization to less than 1%. These requirements by achieved by a simple 2 lens Galilean expander and a Berek's polarizer at the exit of each laser. The beams then have to be steered to a common spot with the angle of incidence needed, with the additional ability to shift as well as tilt the beams independently. Both shift and tilt can be performed by using a single pair of mirrors that act as a periscope. The lasers are mounted parallel to each other in a square pattern (when a Sodium laser is added to the layout). The tip-tilt mirrors sit in a plane perpendicular to the beams and steer them towards a single hub. This hub is the location where the four lasers are tilted into their relative orientations on a 100^{\prime} circle.



Figure 5. The full-fledged optical system for the laser system.

The design primarily uses commercially available components. The mirrors are all high power laser quality fused silica mirrors with a mirror coating optimized for 532 nm. Fold mirror 2, behind which the star camera is located, will be specified to be transmissive in the 810-850 nm range. Most of the optics are selected from the CVI Melles Griot optics catalog. The optical setup is illustrated in Figure 5. The alignment mirrors are large to accommodate possible change in the configuration of the lasers on the sky. This requires a long optical path before the lasers can converge at the pupil. This long optical path, at 1025 mm, is folded using two flat mirrors to reduce the required volume for the optical setup. This inclusion of fold mirrors has a secondary benefit in the form of multiple locations for diagnostic systems behind the mirrors. As the lasers used are very bright, the very small transmission of the fold mirrors (< 0.1%) still provides bright laser beams to use in the diagnostic systems discussed in Section 5.

The desired tilt and tip of each of the two tip-tilt mirrors can be calculated geometrically, and programmed as a matrix multiplication. The non-common optical paths of the three lasers and their independent pointing ability, requires each laser's setup uses its own reference matrix to compute the required tip-tilts. The pupil mirror is mounted on a fast-response piezo tip-tilt platform, and allows for rapid correction of the overall position of the laser star constellation to counter telescope vibrations.

The tip-tilt mirrors are mounted on custom-designed tip-tilt stages that are operated by PI M-227.10 high-resolution linear actuators on each axis. Each of the tip-tilt mirrors has a maximum of 5mm in linear travel at both actuators, translating into a tip/tilt (of the mirror) range of ± 4.5 mm on each axis at the mirror and ± 90 " (of the beam) on sky. However, the size of the aligner mirrors limits the range of movement for the laser beams and the safe range of tip-tilt for the laser beams is only ± 45 " cumulative radially on sky. This implies the need for a software based limit on the maximum allowed deviation of the laser beams based on the combination of positions on all four actuators in the tip-tilt system. The resolution of the tip-tilt stage at the pupil mirror is a PI S-330.4SL stage, and gives a tip and tilt range of 20" on sky with a resolution of 1 mas on sky.

5. DIAGNOSTIC CAMERAS

To help monitor and actively control the pointing of the lasers, diagnostic cameras have been designed as part of the laser system. They do not need any additional optics in the primary laser beams, but will instead utilize the small fraction of laser light that will leak through the fold mirrors. The CCD camera used with all three systems discussed below is model DVC-1500M from DVC Co. This CCD camera has a gigabit ethernet connection that allows full control over a network. The specifications for DVC 1500M are given in Figure 9. The field imager and the pupil imager will include absorptive filters with an OD of about 6 at 532nm to be able to safely image the lasers in an unsaturated form. All cameras have been designed using commercially available catalog lenses with low costs.

The pupil imager is designed to recreate the pupil individually for each of the three laser beams on a single detector so all of them can be monitored without resorting to multiple optical setups or detectors. The pupil is imaged as a disk 340 pixels in diameter, with a plate scale of 23.53μ m/pix at the pupil.

The field imager is designed to keep track of the relative angular positions of the three lasers at the pupil, and monitor for any issues with internal vibrations in the laser system. The plate scale of the image is 31.66 "/pix at the pupil, or 0.63"/pix on the sky. Normal centroiding routines provide better than 0.1 pix of centroiding, which at 0.63 "/pix translates to an accuracy of 0.06" in differential positioning accuracy. Field distortion is less than 0.1% across the field and the desired pointing requirements can be achieved easily.

The star camera is an imaging system that utilizes the laser launch telescope in reverse to image the sky onto a detector. It is a useful feature to have, and if calibrated correctly in the lab, it can be used to align the launch telescope setup with the optical axis of the LBT quickly by using a natural star. The laser launch telescope has a very long focal length aspheric lens designed for 532nm, and thus it is very poor at imaging multiple wavelengths, even a narrow band of 30nm width. The proposed camera counteracts the significant chromatic abberation from the launch telescope to provide a PSF of 3 " over a 30nm band with a 830nm central wavelength. The plate scale is 0.5"/pix, and the imaging is consistent over a 6" \times 6" field. The estimated I-band limiting magnitude of an observable star in a calibrated 1s exposure with the star camera is 13.

6. MEHANICAL DESIGN

The mechanical design of the laser system as a whole is aimed at acting as a rigid structure during operations so that the tip-tilt corrections provided by the telescope systems are effective in countering the telescope vibrations, and internal diagnostics can be depended upon for evaluating the status of the system. The design methodology is based on creating a rigid superstructure in which the optical sub-assemblies can be mounted across a structure where orientation helps negate the effects of external stresses and changes in orientation to enhance stability. As large a fraction of the mechanical components as possible are designed with steel so that issues of differential thermal expansion can be kept to a minimum. The laser system is maintained warm while the telescope, which is made of steel, will be close to the varying ambient temperature. Good insulation is thus essential to maintain that differential.

6.1 Optics to mechanics

The primary optical path in the laser system has only two powered elements, both in the beam expander. They are both held in a single mount that is mounted directly on the laser, thus eliminating the chance of beam defocusing in the system after the alignment. Careful tolerance testing of the optical setup has revealed that the misalignment of the pre-expander is the worst offender in marring the optical performance of the laser system. The mounts and assembly this sub-assembly will receive special care. The single-piece mount to hold the pre-expander is tolerance to an accuracy of 20 m, and the collimator lens position is adjustable during assembly. The assembly of the laser and the pre-expander will be carried out and calibrated with measurements of the exit beam properties to ensure that the quality of the expanded beam is within design specifications.



Figure 6. A cross-section through the center of the laser system box.

The laser beam continues to be collimated when it emerges from the per-expander, and thus changes in the total optical path in the system need not be considered critical. The presence of the tip-tilt mirrors to adjust the pupil position and beam incidence angle provides the system a robustness in its assembly so that any small flexural changes and mismatches can be readily compensated. The laser expanders are all individually calibrated, and the spare laser head is also stored with an aligned expander so it can readily be used as a replacement.

Optical design of the laser system has taken into account the limited space available on the telescope and fold mirrors have been judiciously used to try and spread the mechanical components of the system well in all three dimensions so that assembly and testing will be easy while keeping the overall volume of the system small. The small angular deviation between the output laser beams required the optical design to incorporate a long optical path before the beams could be separated cleanly. This however presented the opportunity to use the laser light that leaks through the mirrors as sources of diagnostics by setting up the diagnostic cameras behind the fold mirrors.

6.2 Subassemblies

The assembly of the laser system has been devolved into an assembly of subsystems. Optical components that act together are assembled into a single mechanical subsystem so that their alignment and testing is easier and changes in the optical

performance will be less likely at the telescope. The pre-expanders are bolted to the lasers. The tip-tilt mirrors are all mounted on a single plate so their inter-dependent operation is better ensured. The optics of the diagnostic cameras are assembled as a single subassembly so that they can be easily tested before the final assembly, and any issues with flexure are greatly reduced by their close mechanical contact through short connections.

The subsystems in the laser system are :

- 1. the lasers with their pre-expanders
- 2. the tip-tilt mirrors and the alignment hub
- 3. the field imager
- 4. the pupil imager
- 5. the star camera
- 6. the launch doublet

The pupil mirror, the fast shutter and the power meter can also be considered a subsystem functionally though they are all independently operated. Identifying these subsystems then helps establish a superstructure that is best suited for the assembly of the entire system.

The lenses and mirrors are mounted with the front surface (ie, facing the optical beam) is positioned against a predefined machined surface, and is held in position by a ring circum-pressed by a spring load from a wavy-washer spring. This reduces load-induced deformations across the optical surfaces, and also reduces the risk of optic dislocation by creating a stable pre-load. All sub-assemblies are positioned using dowel and diamond pins to create repeatable assemblies that are easy to service and replace.

6.3 Superstructure

The superstructure will be a welded steel structure that is rigid can be populated with subsystems and then closed up on all sides with thermally insulating panels to protect the system from dust and insects, and to regulate the temperature in the box. A cross-section through the mechanical setup is shown in Figure 10. The imaging optics of the launch telescope are also mounted and protected within the same box. An exit window at the top of the box is the optical interface between the laser system and the telescope. The superstructure is made of steel ST-33-37 beams 40 x 44 mm in cross section with a 3 mm thick wall.

The superstructure is mounted on the platform with three pods. This helps reduce the stress transmitted from the telescope to the laser box. A panel is also used to insulate the optical space at the laser faces. This is done so that the space that needs to be maintained is smaller and has a cleaner interface. The portion of the superstructure that holds the lasers is separately insulated to maintain them at operating temperatures. The subassemblies are mounted on the superstructure using tabs that are pre-aligned and use pins for repeatable positioning. A cross-section through the near-completion mechanical design of the laser system is shown in Figure 6.

6.4 Thermal / Air control

The specifications of the LBT instrumentation require all equipment mounted on the telescope to be within 1 $^{\circ}$ C from the air temperature. The lasers on the other hand are meant to work at a constant internal temperature of around 20 $^{\circ}$ C. The heat generation from the lasers themselves, and the other electronics in the laser box compel us to insulate the laser box thermally, and to provide for a slow but steady flow of clean dry air through the laser box to maintain the temperature stability as well as the cleanliness of the laser box. A small air cooler with 200W of power equipped with HEPA filters has been chosen for this function.

The insulation used with the laser box is a high-thermal insulation foam held between thin sheets of steel, with impressions and clearances to allow any additional space needed on the interior to accommodate a jutting component (like a tip-tilt actuator). The edges of the insulation panels are inset to form a snug fit to the steel superstructure of the laser box. A soft foam layer forms the interface between the insulation panels and the steel superstructure to form a tight seal to isolate the interior of the laser box from dust and insects and help thermally insulate it. The lasers are mounted on the other side of a partition plate that acts as an insulation wall to keep the bodies of the laser heads outside the filtered area. This reduces the volume that needs to be kept clean by half, as well as reduces the number of cables that have to cross the clean/dirty barrier.



Figure 7. The cryogenic configuration

7. STATUS AND PROGRESS

Following the Final Design Review of the ARGOS project in Fabruary 2010, all the subsystems are being developed at a fast pace. Most of the subsystems of ARGOS will be ready for testing for the later half of 2011, when as many of those systems as possible will be tested at MPE. A telescope simulator is being built at MPE to perform tests on the system to ensure their continued performance at various elevation angles. The design of the simulator is given in Figure 7.

The electronics that will help operate the laser system will be controlled by dedicated drivers and software being written for ARGOS at MPIA. As many electronic subsystems as possible are being homogenized across the ARGOS project to make controlling, testing and operation of the various systems smoother.

REFERENCES

- [1] Rabien, S., Ageorges, N., Angel, R., Brusa, G., Brynnel, J., Busoni, L., Davies, R., Deysenroth, M., Esposito, S., Gässler, W., Genzel, R., Green, R., Haug, M., Lloyd Hart, M., Hölzl, G., Masciadri, E., Pogge, R., Quirrenbach, A., Rademacher, M., Rix, H. W., Salinari, P., Schwab, C., Stalcup, Jr., T., Storm, J., Strüder, L., Thiel, M., Weigelt, G., and Ziegleder, J., "The laser guide star program for the LBT," in [Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series], Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 7015 (July 2008).
- [2] Busoni, L., Esposito, S., Rabien, S., Haug, M., Ziegleder, J., and Hölzl, G., "Wavefront sensor for the Large Binocular Telescope laser guide star facility," in [Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series], Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 7015 (July 2008).