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STATUS OF ARGOS - THE LASER GUIDE STAR SYSTEM FOR THE LBT

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Abstract. ARGOS is an innovative multiple laser guide star adaptive optics system for the Large Binocular Telescope (LBT), designed to perform effective GLAO correction over a very wide field of view. The system uses high powered pulsed green (532 nm) lasers to generate a set of three guide stars above each of the LBT mirrors. The laser beams are launched through a 40 cm telescope and focused at an altitude of 12 km, creating laser beacons by means of Rayleigh scattering. The returning scattered light, sensitive primarily to the turbulences close to the ground, is detected by a gated wavefront sensor system. The derived ground layer correction signals are directly driving the adaptive secondary mirror of the LBT. ARGOS is especially designed for operation with the multiple object spectrograph LUCI, which will benefit from both the improved spatial resolution, as well as the strongly enhanced flux. In addition to the GLAO Rayleigh beacon system, ARGOS has also been designed for a possible future upgrade with a hybrid sodium laser - Rayleigh beacon combination, enabling diffraction limited operation. The ARGOS laser system has undergone extensive tests during Summer 2012 and is scheduled for installation at the LBT in Spring 2013. The remaining sub-systems will be installed in the course of 2013. We report on the overall status of the ARGOS system and the results of the sub-system characterizations carried out so far.

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1 Introduction

ARGOS [1–4] is a Rayleigh beacon, ground layer adaptive optics (GLAO) system for wide field corrections, specially tailored for the two LUCI [5–7] instruments, which provide wide field imaging and multi-object spectroscopy in the near infrared waveband at the LBT. Capitalizing on special design of LBT's AO system featuring large-scale adaptive secondary mirrors, ARGOS will significantly improve the resolution and sensitivity for both imaging and multi-object spectroscopy over the full four arcminutes field of view of the LUCI instruments. In addition, the ARGOS will also increase the signal to noise ratio for spectroscopic observations by concentrating the flux in LUCI's MOS slits. Figure 1 shows the result of various independent performance calculations carried out within the ARGOS consortium. The simulations consistently show a decrease of the FWHM by a factor of $2-3$, leading to an increase of the flux in the 0.25 arcsec slits of LUCI. This increase in flux translates directly to a gain of $4-9$ in observing time. The overall increase in resolution and sensitivity will reduce the required observing time or - in certain cases - even enable observation and characterization of faint objects previously unaccessible by LUCI.

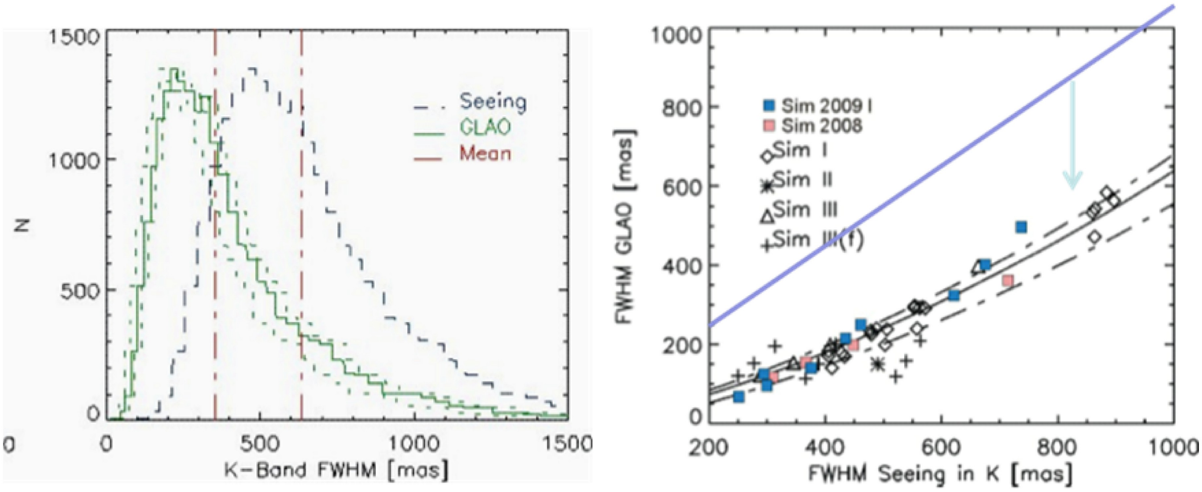

Fig. 1. Predicted performance of the AGROS system. Left panel: expected FWHM in the GLAO corrected field as a function of seeing limited FWHM. Right panel: the seeing curve (taken at Mt. Hopkins) in comparison with a curve folded with the ARGOS simulated performance.

2 System Overview

Since the ARGOS system will be used to correct the wavefronts of each of the two LBT telescope, two nearly independent systems will be operated on each of the LBT telescope. Figure 2 shows a schematic representation of one unit of the ARGOS system.

The laser system contains three high-power, Nd:YAG lasers frequency-doubled to emit at a wavelength of 532 nm. All three lasers produce a short ∼40 ns laser pulse,synchronized to a common trigger signal. The laser pulses are then pre-expanded, steered to the appropriate locations in the focal and pupil planes and propagated to the laser launch system.

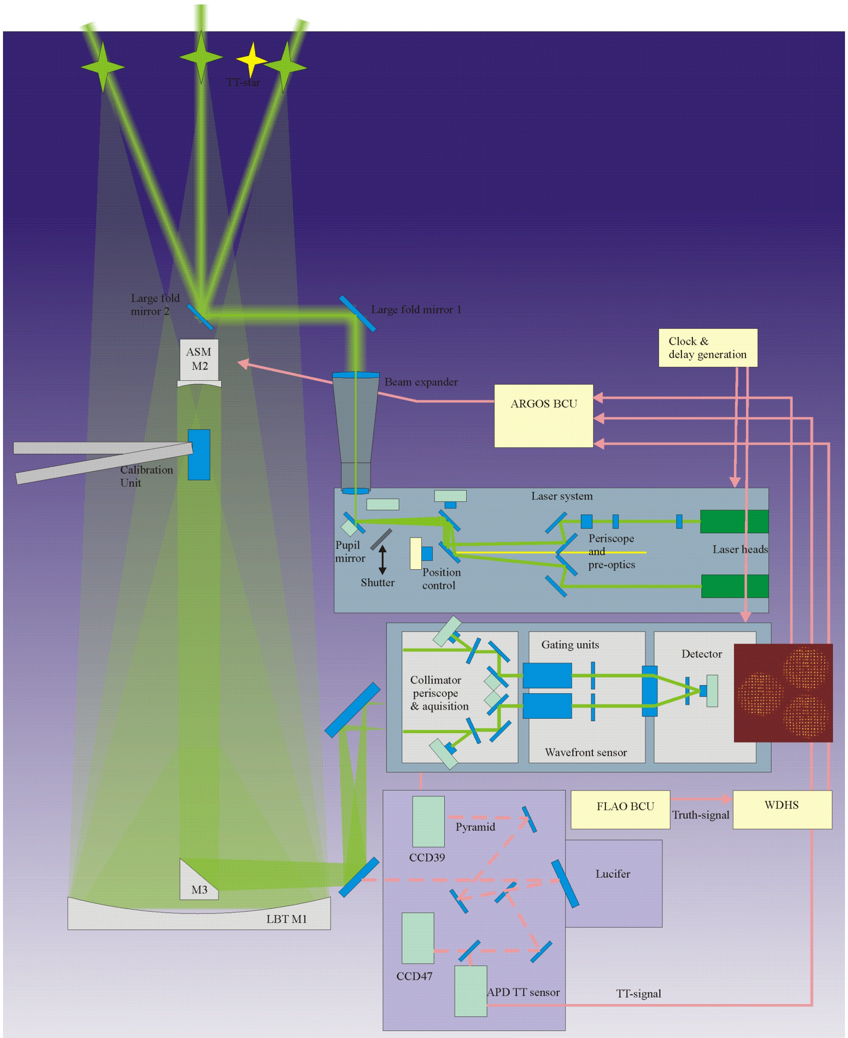

Fig. 2. Overview of the ARGOS system.

The laser launch system then expands the beams to a diameter of ∼40 cm and propagates the pulses on sky via large folding mirrors. In addition, the refractive optics of the launch system focuses the laser beams at an elevation of 12 km. After a total flight time of 80.06 μs, the photons scattered at 12 km arrive back at the telescope, where a dichroic beam splitter reflects the returning laser photons to the wave front sensor system. Within the Shack-Hartmann based wave front sensor system, gated shutters open for 2 μs, effectively "cutting out" columns of light roughly 300 m long. The gated light from all three laser guide stars is then imaged through a lenslet array onto a single low-noise detector array. A dedicated computation unit (ARGOS BCU) calculates the wave front error from the slopes of the wave front sensor signals and feeds the correction signals directly into the LBT adaptive secondary mirror. In addition, light from a natural guide star is picked off by the tip-tilt and truth sensor system, located in the so-called guider and wavefront sensing system (AGW), directly in front of the LUCI entrance window. The tip-tilt and truth sensor system uses a quad-cell avalanche photodiode system to generate a fast tip-tilt correction signal and also acts as a truth sensor, measuring the lowest ∼10 orders with the first light AO pyramid wavefront sensor operated at a low frequency.

Implementation of the ARGOS system is scheduled around a series of milestones: the laser system installation was successfully installed in April 2013. We expect first projection of a laser beacon on sky in October 2013, with the dichroics and wavefront sensors installed in February 2014. First detection of the laser guide stars on the wavefront sensors and alignment/optimization of the system is planned for April 2014, followed by an extensive commissioning and science verification phase throughout 2014. The ARGOS GLAO system will then be available for routine observations in early 2015.

The following sub-sections will describe the individual components in closer detail and expand on the actual status of the respective development efforts:

2.1 Laser System

Each of the two (SX and DX side of the LBT) laser systems [8,9] of ARGOS comprises three 18 W pulsed lasers with beam pre-expanders and $\lambda/2$-plates used to adjust the polarization of the laser beams. Each beam is propagated through a set of tilt-able periscope mirrors which control the position of the individual laser guide stars within the constellation. An additional piezo controlled, fast tip-tilt mirror, mounted at the location at which all three beams coincide, is used to control the position of the entire constellation on sky. Each laser system also contains a laser beam diagnostic systems, consisting of fast photo diodes to detect the individual laser pulses and a laser power meter for quick laser health checks, as well as a low power alignment laser defining the center of the laser guide star constellation. Each laser system is housed in a hermetically sealed and thermally controlled enclosure known as the "laser box". A picture of one of the laser boxes is shown in Figure 3.

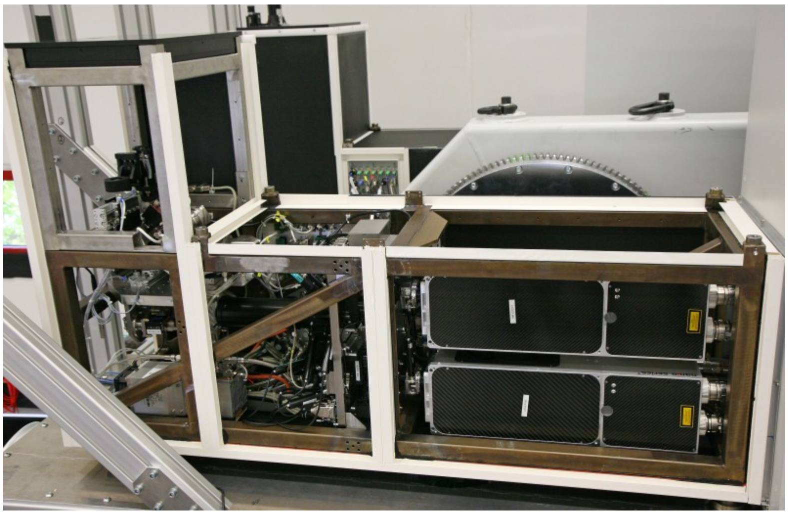

Fig. 3. Picture of one of the ARGOS laser boxes (The outer insulation panels are partially removed).

The ARGOS laser system was successfully installed at the LBT observatory in April 2013. Extensive functional tests have been carried out and have verified the operation of the systems according to specifications. The alignment of the laser system with respect to the launch telescope was carried out during a second run in June 2013. A picture of the installed laser system is shown in Figure 4.

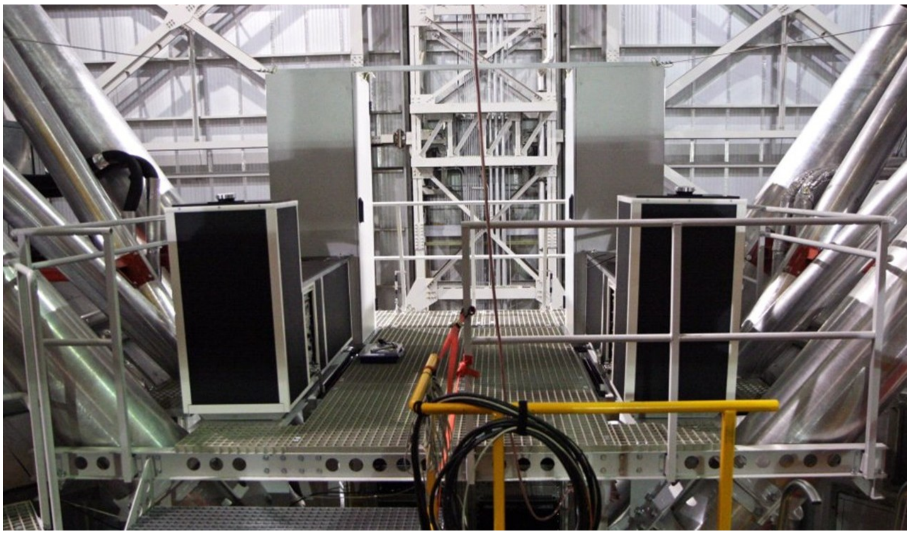

Fig. 4. The ARGOS laser system mounted on the laser launch platform of the LBT.

2.2 Laser Launch System

The laser launch system [10] is a refractive, aspheric beam expander system designed to expand the laser beams to a diameter of ∼40 cm. The beam expander system is followed by a set of two flat fold mirrors which direct the beams onto the sky from behind the secondary mirrors of the LBT telescopes. The first of these two launch mirrors can be tilted along both axes to allow compensation of telescope flexure. All optical elements are coated to provide highest transmission at the wavelength of the Rayleigh beacons (532 nm) as well as the wavelength of a potential sodium laser (589 nm) guide star upgrade (see section 3). The laser launch system will focus the laser beams at an altitude of 12 km, creating a constellation of laser guide stars around a 4 arcmin diameter circle. The exact location of the individual guide stars within the constellation can be adjusted with a 0.5 arcmin radius by the periscope mirrors of the laser box (see section 2.1). The entire optical system is protected by dust tubes installed between the laser boxes and the large second lens as well as a set of pneumatically operated dust shutters, effectively preventing contamination of the optical surfaces.

All optical and opto-mechanical components were installed at the observatory by March 2013 and are ready for operation. Parts of the dust cover system are still in the design or manufacturing phase respectively and are expected to be ready for installation in Fall 2013.

2.3 Dichroics and Wavefront Sensing System

The laser light returning from the guide star beacons is split off from the visible (used for guiding and truth control) and the infrared science light by large dichroic beam splitters located close to the entrance to the LUCI instruments. A sputtered dielectric coating guarantees high reflectivity at 532 nm (Rayleigh beacons) and 589 nm (sodium upgrade) and high transmission outside these two bands. A complete re-design of the mechanical arrangement of the dichroic system now ensures minimal distortions of the science field after passing the field de-rotator structure. The mechanical layout of the fully retractable dichroic system is shown in Figure 5.

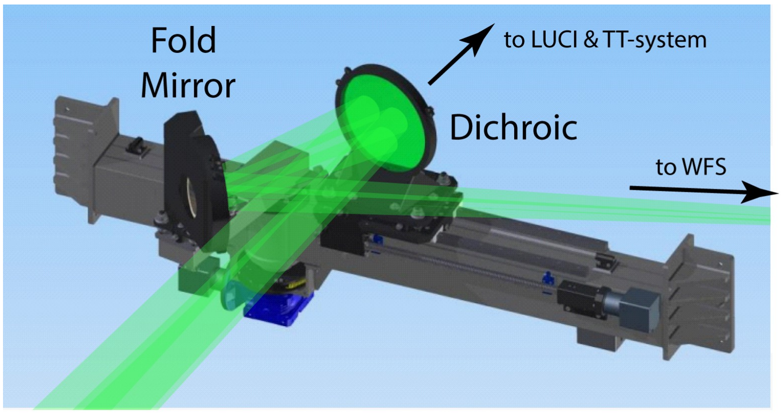

Fig. 5. 3D model of the newly designed "low-incidence" dichroic mechanism.

After being reflected by the dichroic beam splitter, the laser light enters the wave front sensor system [11,12], where the individual beams first pass through a collimator and a set of piezo activated tip-tilt mirrors. These mirrors are operated in closed loop and compensate for any residual beam jitter. The collimated light is then gated with a set of three electro-optical Pockels cell shutters, transmitting only light scattered within a ∼300 m column around the nominal laser beacon hight of 12 km. A combination of off-axis relay optics and an on-axis collimator system arranges the light onto a single lenslet array and the detector of the Shack-Hartmann based wavefront sensor. The wavefront sensor detectors [13–15] themselves are deep depletion PnCCDs, custom-built by the then Max-Planck owned Halbleiterlabor and PNSensor. The 248×256 pixel detector arrays have a read noise of 3 – 4 e^- at a quantum efficiency of near unity and allow read-out frame rates of up to 1 kHz. At a laser pulse repetition rate of 10 kHz, this means that the signal from 10 consecutive laser pulses is collected during a single exposure. A Microgate BCU is used for real time slope computing and wavefront reconstruction.

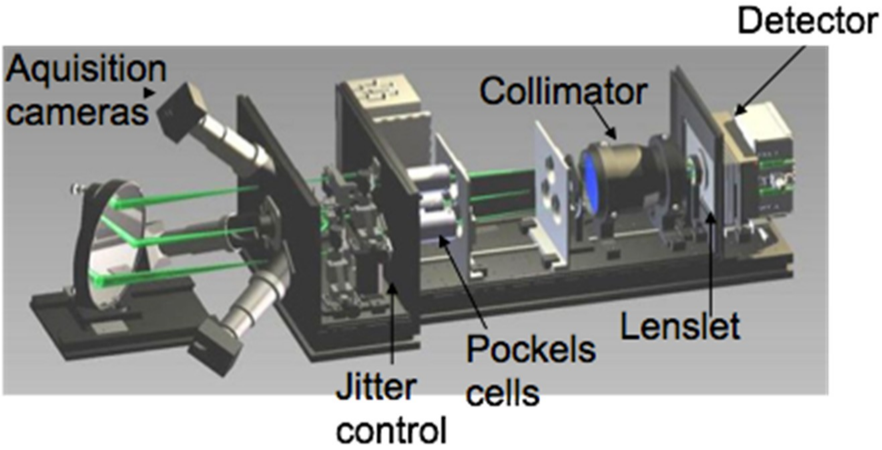

Fig. 6. Schematic view of the wavefront sensor system.

Delivery of the dichroic mirrors and dichroic mirror mechanisms is expected in August 2013 followed by a period of extensive testing. Installation of the system is planned for November 2013. The wavefront sensor of one side has been fully assembled and system testing has started. Assembly of the second wavefront sensor is under way. Both systems are scheduled for installation at the LBT early 2014.

2.4 Tip-Tilt and Truth Control

The tip-tilt control system of ARGOS is designed as an extension of the existing natural guide star pyramid wavefront sensor. The system is based on a fiber fed APD Quadcell sensor operating with ∼90% of the light of the natural guide star picked off on the so called w-board of the first light AO (FLAO) system. The remaining 10% of the star light is guided to the original FLAO pyramid sensor operated at a significantly reduced frame rate. The slow signal is still sufficient to calculate the first ∼10 low order modes which are used for truth sensing.

As of June 2013, a complete set of fiber bundles as well as the 2x2 lenslet arrays have been manufactured and delivered. The critical step of aligning the fiber bundles to the lenslet arrays has yet to follow and is planned for Summer 2013. The installation of the tip-tilt/truth control system requires modifications to the "acquisition guiding and wavefront sensing" (AGW) units, which are normally only accessible when the LUCI instruments are not at the telescope. Installation might therefore only be possible during scheduled summer shutdowns.

2.5 Calibration System

The ARGOS system will feature two deployable calibration units [16] designed to allow efficient alignment and calibration of the wave front sensors during day time. The calibration sources are mounted on carbon fiber swing arms that move the units into the respective prime focus of the Gregorian type LBT telescopes. The calibration system can produce an on-axis beam through reflection of a light source in the center of the secondary mirror and three off-axis beams, which are generated internally. The calibration units themselves are a hybrid optical system with conventional lens elements and a computer-generated hologram to simulate the off-axis aberrations of the laser guide stars.

Both swing arms have been mounted at the LBT and are fully functional. The design of the so-called swing arm harbors, which provide protection for the sensitive optical elements is nearing completion. All mechanical and optical components of the calibration sources have been manufactured and delivered. Assembly and final testing of the sources is scheduled for Summer 2013.

3 Future Upgrade Path

A potential upgrade path towards diffraction-limited operation has been an important consideration since the early design stages of ARGOS. The addition of a sodium laser to the existing system would provide such an upgrade [17,18]. Figure 7 shows a schematic representation of the proposed hardware. High-order and high-speed correction of the ground layer is already performed by the Rayleigh lasers guide stars, which deliver a large number of photons to the wavefront sensor under a wide variety of atmospheric conditions. The remaining distortions originating from higher atmospheric layers are typically of a much larger scale, allowing this high layer detection to be sampled over larger sub-apertures. Consequently, much reduced sodium laser power is required for effective sampling of those sub-apertures, as compared to a “classical” sodium laser AO system.

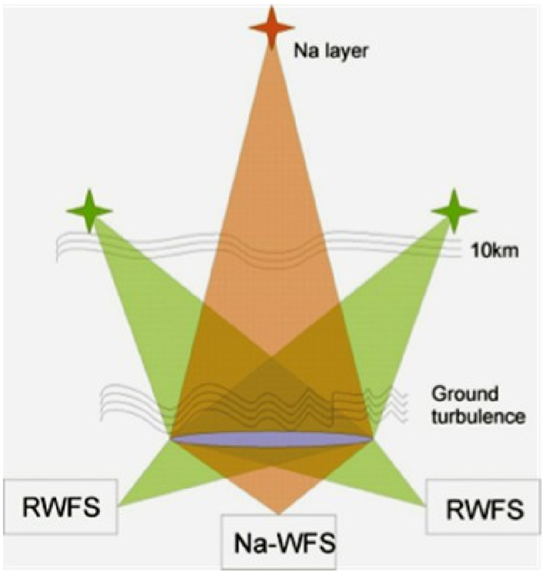

Fig. 7. Schematic view of a possible upgrade to a hybrid laser guiding system.

Space for an additional sodium laser is available inside (or on top of) the current laser system and an optical path has been prepared and held clear for the required optics. Sufficient space is also available inside the wavefront sensor system to allow the installation of an additional 589 nm wave front sensor and the required optical components.

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