ARGOS the Laser Star Adaptive Optics for the LBT

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Abstract. ARGOS - the Laser Guide Star adaptive optics facility for the Large Binocular Telescope will enable a wide field high order ground layer correction of the atmospheric induced distortions. By projecting a constellation of multiple laser guide stars above each of the 8.4m primary mirrors of the LBT, ARGOS in its ground layer mode will enable a wide field adaptive optics correction for multi object spectroscopy. ARGOS implements high power pulsed green lasers and makes use of Rayleigh scattering for the guide star creation. The geometric relations of this setup in guide star height vs. primary diameter are quite comparable to an ELT with sodium guide stars. The use of LBT's adaptive secondary mirror, gated wavefront sensors, a prime focus calibration system and the laser constellation shows several aspects that can be used as path-finder technology for the planned ELTs. In already planned upgrade steps with a hybrid Sodium-Rayleigh combination ARGOS will enable MCAO and MOAO implementations at LBT allowing unique astronomical observations.

1. Introduction

The ARGOS laser adaptive optics facility is being initiated by the LBT partner institutions from Germany, Italy and the US. As a common goal a wide field adaptive optics correction has been recognized as an enabling technology for a multitude of science cases. As a high profile example galaxy evolution studies will benefit greatly from an enhanced resolution and increased encircled energy over a large field of view, as provided by ARGOS [1,2].
The LBT telescope itself provides the observer with two 8.4m size apertures, adaptive secondary mirrors for the atmospheric correction and a suite of instruments for imaging and

spectroscopy over a large range of wavelength. Wide field imaging and multi object spectroscopy in the near infrared, as a key observing tool for high redshift objects, is provided by the LUCI instruments. [3,4]

In its first instance ARGOS is tailored to enhance the observing capabilities for this wide field instrument. Thus the corrected field will span over the full four arcminutes field of view for imaging studies. Enhancing the flux in the MOS slits the signal to noise ratio is increased for spectroscopic observations. This will significantly reduce the required observing time - or even enable observations of faint objects that could not be detected otherwise.

In terms of technology ARGOS will rely on laser guide stars, thus ensuring that nearly any spot in the sky can be observed irrespectively of natural guide star asterisms, as required by NGS wide field AO. Utilizing the Rayleigh scattering from high power green laser pulses ARGOS will ensure a reliable and stable photon flux for wavefront sensing, enabling routine operation in most atmospheric conditions. The constellation of three laser guide stars above each of the LBTs primaries will be detected with Shack Hartmann based wavefront sensors. Those sensors include mechanisms for acquiring, picking and stabilizing the laser spots on the sensor, gating out the required guide star height with Pockels cells and imaging all subapertures of the three guide stars on a single large frame CCD detector. Other subsystems that are mandatory for the successful operation of a LGS system are: a tip-tilt sensor and control, a calibration system, a closed loop realtime computing unit and proper instrument control software.

Additionally to the ground layer correction, ARGOS is prepared to implement a second step that will lead to diffraction limited operation and paves the way to MCAO implementations at LBT. Adding a central sodium guide star in hybrid constellation to the low altitude Rayleigh stars will probe the turbulent volume above the telescope and allows immediately to correct on-axis with a single conjugated setup. The great pro of this setup are the powerful green Rayleigh stars, helping to clean up the strong ground conjugated distortions, thus leaving a relatively easy task for the sodium laser setup.

In the ELT context, LBT with its adaptive secondary mirrors, the permanent ground layer correction with the constellation of laser stars allows us to test several important aspects before implementing those at ELTs. E.g. questions like: how strong is the ground layer over the years and seasons? How much of the distortions can be removed under which conditions? What spot elongation can be tolerated on the WFS – or what additional means are required for a reliable and stable ground corrected adaptive telescope?

2. Science cases

A variety of science programs will benefit from enhanced resolution and increased slit coupling efficiency. With multiple studies and model calculations the performance of the ARGOS ground layer adaptive optics has been calculated. Figure 1 shows what can be expected from such a system.

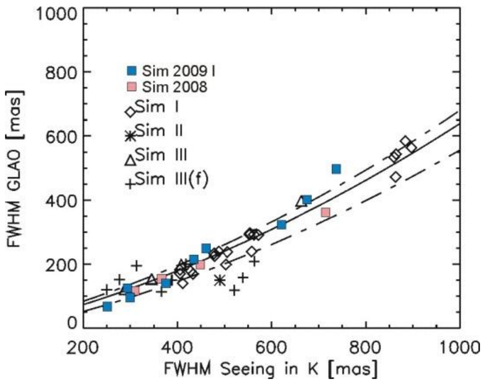

Fig. 1 : Expected performance of the LGS constellation based adaptive optics correction. Shown is the FWHM of the PSF corrected by the GLAO system over the Seeing. With multiple independent simulation packages a consistent picture arises, predicting a PSF size reduction by a factor 2-3.

In summary the decrease in PSF size should be around 2-3 and will depend on the seeing, and especially on the power in the high layer turbulence. Therefore ground layer correction could be characterized as a ‘seeing enhancer’, making a bad night acceptable and a medium night excellent. Consequences of a GLAO correction are:

- Increased point source sensitivity
- Increased slit coupling efficiency for spectroscopy
- Reduced crowding noise in dense fields
- Enhanced spatial resolution

When initiating ARGOS for the LBT a poll amongst the community has shown a great interest and brought up a lot of science cases that exactly require GLAO image enhancement. Amongst others, cases are ranked around:

- Dynamics & stellar populations in high redshift galaxies
- Post starburst clusters in the Milky Way
- Star formation in nearby galaxies
- High resolution imaging in local group star bursts

Regarding high redshift galaxies, as a highlight science case, many questions are still open:

- how were galaxies built up (mergers vs slow accretion)?
- how did galaxies acquire their morphology (bulges, disks, ellipticals)?
- how did galaxies get their angular momentum (disk sizes)?

Indeed the latter case is challenging for normal observations, since high redshift galaxies are clearly too small for seeing restricted resolution, but as well too faint for diffraction limited work.

The requirements for optimum observations are clearly:

- *GLAO resolution* as trade-off between spatial scales & S/N; 0.25” ~ 2kpc
- *near-IR* to probe the rest frame optical
- *spectroscopy* to measure emission line flux, distribution, & kinematics
- *wide field capability* for multiplexing & large samples

which is exactly what will be provided by ARGOS & LUCI at the LBT.

3. System layout

Figure 2 shows a sketch of how the ARGOS system is set up and functioning. In a laser system three high power diode pumped solid state laser modules are housed. Upon a trigger command all laser heads are firing synchronously a ~40ns wide 532nm light pulse. Within the laser box the beams are first expanded to some mm width and then directed to a pupil mirror at the lower end of the launch telescope. With the optics in the laser box the pointing direction of the laser beams and the polarization direction is adjusted.
Travelling through the launch telescope, the beams are expanded and focused to a 12km distance. After the refractive beam expander two large lenses fold the beams to behind the secondary and from there towards sky. While travelling through atmosphere, some photons out of the pulse will be scattered by air molecules. After 80.06µs the photons scattered at a 12km distance arrive back again at the telescope.
In front of the LUCI rotator and guiding units we separate off those photons with a dichroic beam splitter and direct the light towards the ARGOS wavefront sensor. Inside the WFS the beams are first collimated and brought a bit closer to each other. A PZT driven mirror enables a fast correction of the uplink and vibration induced jitter. In the following, Pockels cells gating units slice out exactly those photons being scattered at 12km distance, within a ±150m range. The light out of this limited volume then falls through the lenslet array onto the detector. The detector itself is a fast large frame PnCCD [7] allowing all three laser guide stars to be imaged on a single frame. With the lasers running at a 10kHz repetition rate the Pockels cells will be triggered at the same rate. The detector accumulates the photon bunches from ten pulses and is commanded to read out then every millisecond.
The frames from the CCD are transferred to the ARGOS slope BCU. This computer calculates the centroid position of all spots and sends the resulting slope vector to the adaptive secondary mirror where the reconstruction is performed.
Since the laser guide star position as measured on sky does not reflect the atmospheric tilt, a separate tip-tilt sensor is required. After re-calculating the performance of several possibilities we have chosen to setup an APD based system. The light for this APD quad cell is picked on the w-unit of the first light AO. Additionally some small amount of the natural guide star light is directed to the pyramid wavefront sensor of the FLAO. This signal will be used to sense ~10 modes and slowly offset the laser guide star wavefront slopes. The purpose of this truth sensing is to adapt for non-common path aberrations, imperfect calibrations and the slight difference between elongated spots on sky and round calibration spots.
In figure 2 on the left side the sketch of an additional swing arm is drawn. Those swing arms we will be able to move a small optics barrel close to the prime focus of LBT. This barrel enables us to calibrate the system, mimicking the laser stars as appearing on sky. This calibration source enables a full system and DM calibration during daytime, saving precious nighttime for observing. [5]

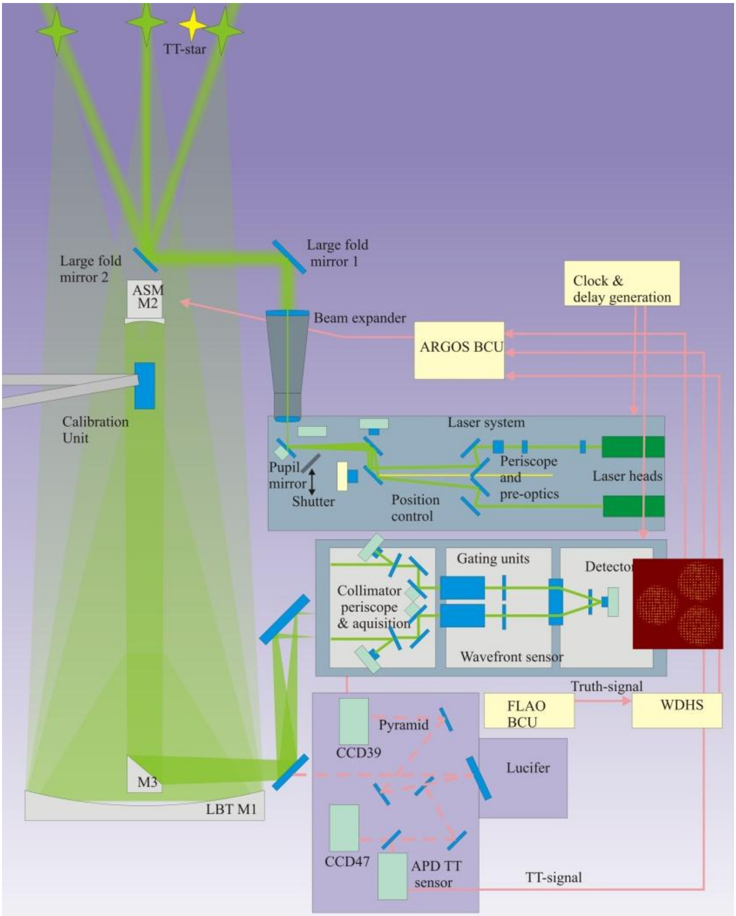

Fig. 2 : Scheme of the ARGOS laser and WFS facility, shown for one of the two identical binocular sides. In the laser system the high power green laser pulses are generated, steered to the proper angular separation, adapted in polarization and fired via the beam expander and launch system to sky. The scattered light is detected back on the Wavefront sensor, containing aquisition and beam stabilization optics, the gating units and a large frame, low noise fast detector for the Shack Hartmann spots. A central clock and delay generator controls the overall timing of pulse firing, Pockels cell control and detector readout.

4. Laser system

In a nutshell the ARGOS laser system consists of two units, one for each side of the binocular telescope, containing three lasers each. The lasers themselves are commercial frequency doubled Nd:YAG systems, emitting <40ns light pulses at an average power of 18W. The repetition rate is controlled by an external clock and delay generator applying ~10kHz trigger signals. Using one laser head for each laser beacon, the position of each spot can- and has to be- controlled individually to track flexure and center the spots on the WFS sub-apertures. This task is taken by a motorized periscope controlled in closed loop via a field and a pupil imager inside of the system.

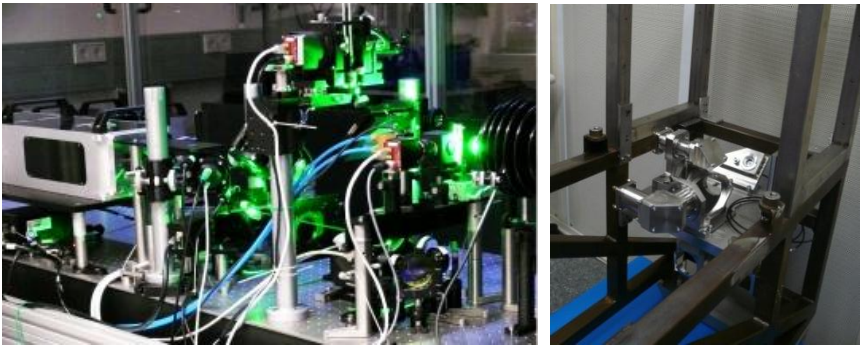

Fig. 3: In a first test setup one of the six laser heads is put into the beam steering and control optics on an optical bench. With this test the beam position control, safety features and software can be tested. To the right the first mechanical assembly for the beam diagnostics in the final frame is shown, providing a rigid structure.

With the back detection of the scattered laser light being done with Pockels cells as gating units, we have chosen to launch the laser light linearly polarized, properly adjusted with a half wave plate to the receivers acceptance direction. Additional infrastructure we have found necessary for a successful laser operation is added to the system: a cover that seals off the optics from the dusty and variable telescope environment, a temperature control system to ensure constant conditions for the lasers, a power meter and a collimation tester for system health check, a star imaging camera and an on axis alignment beam to ease setup.
When leaving the laser system the beams are caught by the launch optics, expanded to a 40cm beam and steered with two large mirrors behind the LBTs secondary and from there to sky. Within this ‘launch system’ a standalone vibration compensation system ensures that the spots on sky are not influenced by windshake and other unwanted wobble of the folding mirrors.

5. Wavefront sensing and real time control

A CAD view of the wavefront sensor is shown in Fig. 4. This unit receives the scattered light from the lasers splitting the green light off in front of the science instrument [6]. The basic principle of the WFS follows a Shack Hartmann setup, spanning a 15 sub-apertures across the pupil. With the beam path being send through an entrance aperture with 4’’ diameter and Pockels cells to discriminate the desired 300m column photons from other scattering, sharp spots are expected on the detector, resulting in precision wavefront measurements. The detector itself consists of a 264x264 pixel array readable at a 1 kHz framerate with a ~3 e- noise [7]. Additional means in the sensor ensure a smooth implementation and operation at the telescope: wider field acquisition cameras for an automatic guide star catching, a fast PZT to remove global tilt jitter from the spot patterns, internal alignment sources mimicking the laser guide stars and even a small micro deformable mirror to simulate turbulence on those sources.

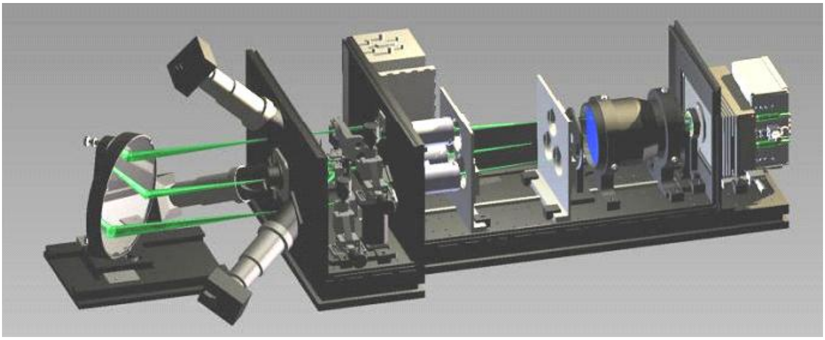

Fig. 4: CAD view of the ARGOS wavefront sensor. The green beam from the three laser guide stars enter from the fold mirror seen to the left. At the entrance of the WFS three acquisition cameras ensure that the beacons are always seen and can be steered to the entrance aperture if being out when acquiring a new object. After a first actuated periscope Pockels cells gate out the desired column of scattered light and a collimator brings the beams onto the WFS directly in front of the detector, seen on the right side of the picture.

The frames read from the detector are transferred to a BCU 'basic computational unit', a DSP/ FPGA based real time computer that performs the basic image reduction steps, extracts the slopes from the sub-apertures, adds the tip-tilt signal from the APD tracker and optionally the slopes from a high altitude sodium guide star. From there the slope vector is transferred to the LBT secondary mirror BCUs for phase reconstruction and for finally setting the shape of the deformable thin shell.

6. Hybrid laser guiding

With its constellation of guide stars, the correction over a large deformable secondary, a permanent ground layer correction of the 'adaptive telescope', LBT with ARGOS shows many features that are planned as well for the upcoming generation of extremely large telescopes. Apart from the experience that one can get with the existing system and apply to an ELT, ARGOS at the LBT is planning for upgrades that might be interesting on an ELT scale as well. To allow the step from ground layer adaptive optics to diffraction limited performance we are planning to implement a sodium line laser on top of the Rayleigh stars [8]. This setup shows some unique advantage making it an attractive solution:

- The Rayleigh lasers will deliver a huge number of photons to the wavefront sensor in a wide variety of atmospheric conditions. This enables a high order and high speed correction of the ground layer.
- The remaining atmospheric distortions that need to be cleaned up are of larger scale, allowing the high layer detection to be sampled over large sub-apertures, permitting lower power sodium lasers.

- Using a constellation of stars at low altitude in conjunction with one –or more- sodium guide stars at large distance one can break the low order mode degeneracy that appears in MCAO systems with guide stars at the same height. This removes the need for multiple tip-tilt stars, thus greatly helps in gaining sky coverage.

With the elements at hand – deformable secondary, a constellation of Rayleigh lasers, the planned central sodium laser(s), the tip-tilt tracker and a truth sensing capability – all ingredients for detailed studies are at hand concerning ground layer correction efficiencies, operational scenarios, tomographic measurements or multi conjugate adaptive systems.

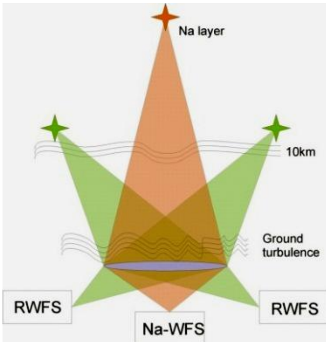

Fig. 5: sketch of a hybrid laser guiding scheme. Low altitude Rayleigh laser guide stars sense the strong ground layer turbulence and allow a fast high order correction. Adding a central sodium laser or constellation of sodium stars gives access to the high altitude turbulence, paving the way to diffraction limited operation, MCAO applications or tomographic sensing schemes.

In the ELT context the ARGOS at the LBT offers a unique possibility to practice required technologies or even test new sensing schemes like dynamical refocusing on Rayleigh and Sodium lasers or sensing laser guide stars with pyramid sensors [9].

7. References

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