The Laser Guide Star Program for the LBT

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ABSTRACT

Laser guide star adaptive optics and interferometry are currently revolutionizing ground-based near-IR astronomy, as demonstrated at various large telescopes. The Large Binocular Telescope from the beginning included adaptive optics in the telescope design. With the deformable secondary mirrors and a suite of instruments taking advantage of the AO capabilities, the LBT will play an important role in addressing major scientific questions. Extending from a natural guide star based system, towards a laser guide stars will multiply the number of targets that can be observed. In this paper we present the laser guide star and wavefront sensor program as currently being planned for the LBT. This program will provide a multi Rayleigh guide star constellation for wide field ground layer correction taking advantage of the multi object spectrograph and imager LUCIFER in a first step. The already foreseen upgrade path will deliver an on axis diffraction limited mode with LGS AO based on tomography or additional sodium guide stars to even further enhance the scientific use of the LBT including the interferometric capabilities.

Keywords: Laser Guide Stars, Ground Layer Adaptive Optics, Large Binocular Telescope

1. INTRODUCTION

The LBT laser guide star program is an initiative being launched by a consortium of the LBT partners to equip both eyes of the Large Binocular Telescope with an up to date laser and wavefront sensing capability in a staged approach. A first implementation of a laser beacon ground layer correction system will strongly increase the scientific return and efficiency of the LUCIFER instrument, a wide field imager and multi-object spectrograph. In contrast to the approach taken at most 8-10m telescopes, the wide field correction of the GLAO system will allow the full field, as large as 4x4 arcminutes, to benefit from adaptive optics correction. The expected scientific gain described in section 2 shows the importance of such a system to major scientific questions. The combination of GLAO with MOS leads to an instrument being even more sensitive than JWST between the OH lines at R~3000 and shows a high multiplex advantage. The topics for which ground layer adaptive optics shows major benefits, reach from extragalactic cases as: dynamics and stellar populations of high redshift galaxies, QSO host galaxies, M31 and z>6 objects to galactic astrophysical questions like planets, cepheides and stellar clusters.

While single conjugated adaptive optics delivers high strehl ratios on axis, this method suffers generally from angular anisoplanatism. Only a small field over the isoplanatic patch is well corrected with the performance degrading towards the edges quickly. Ground layer adaptive optics [1], utilizing multiple laser guide stars is generally capable of correcting

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a larger field of view. This technique has been demonstrated already with the use of natural stars. Multi laser systems are in the process of installation or commissioning at the MMT [2] and Gemini [3] telescopes.

Ground layer adaptive optics offers some general benefits which are not associated with reaching the diffraction limit. The advantages here lie in the enhanced resolution, the increased point source sensitivity and slit coupling efficiency as well as the robustness against crowding. Offering those advantages over a large field of view makes up the uniqueness and is planned for the installation at the LBT telescope.

Basing the scientific gain that is expected from the implementation of a laser facility on solid calculations, the possible performance of a laser guided GLAO system has been analysed with extensive modelling. Chapter 3 summarizes the outcome of three independent models of a multi-laser GLAO system, based on atmospheric conditions as expected for Mount Graham.

In a second step of our approach we already foresee upgrade paths from a GLAO system to an on axis diffraction limited mode with LGS AO. This can be based on tomography and additional sodium guide stars. The system as foreseen in a first implementation, takes those possibilities into account, leaves space to easily install those capabilities in a second step. Using this staged approach will allow LBT to quickly become very competitive with other large facilities in terms of scientific output and paves the road to unique observations in wide field high resolution studies and enhancement of the interferometric capabilities towards faint object science.

The LBT with its first suite of instruments coming online hosts capabilities unique in the world. LUCIFER, an imager and spectroscopy instrument will see first light in 2008. The available observing modes allow for:

- diffraction limited imaging
- wide field imaging over 4x4 arcmin
- long slit spectroscopy
- multi-object spectroscopy over 4x2 arcmin

LINC/LBTI, foreseen to be commissioned > 2009, will deliver high resolution studies of single targets and wide-field studies in the interferometric mode of the LBT.

These LBT capabilities have led to a consensus within the LBT partners onto the program goals for the LBT laser guiding facility:

- exploit the scientific competitive edge of LUCIFER MOS and wide field imaging,
- implement a reliable, low maintenance system with low risks and minimized changes to existing telescope systems, capable of operating significantly above median atmospheric conditions
- realize a ground-layer system improving the image FWHM and energy concentration for spectroscopy.
- identify an upgrade path to diffraction limited performance

The foreseen system as described in this paper takes those recommendations into account, by planning for a multi Rayleigh laser guided ground layer correction, allowing for a fast implementation and suitable upgrade possibilities.

2. SCIENCE CAPABILITIES WITH GROUND LAYER ADAPTIVE OPTICS

The implementation plans for laser guide star adaptive optics followed by most 8-m class observatories – specifically including Keck [4], VLT [5][6], Subaru [7], and Gemini [8] – have begun with a single sodium laser and single-conjugate adaptive optics. This provides diffraction limited performance over a rather small (~20") field of view. Such LGS-AO observations have been proceeding for 2 years or more with the Keck telescope, and more than 1 year on the VLT.

In contrast to this, the ground layer laser guide star adaptive optics system on the LBT aims at providing enhanced resolution and sensitivity for both imaging and multi-object spectroscopy *over a very wide field of view*. The LGS-GLAO system described in this paper will provide a resolution comparable to that of HST/NICMOS (0.2arcsec in the K-band) over a full 4arcmin field of view. This remarkable performance will greatly boost the capabilities of LUCIFER, the instrument for which it is primarily conceived. Indeed, it is the increase in speed (to reach a given signal-to-noise) for LUCIFER's wide field MOS capability that makes GLAO such a compelling choice for the LBT. The complementarity of this combination to currently operational AO systems will make near infrared observations on the LBT extremely competitive with those attainable at other world-class observatories. There are a number of different ways in which LGS-GLAO will directly benefit observations, and these are outlined below.

Increased Point Source Sensitivity and Slit Coupling Efficiency

The most obvious, and most frequently touted, advantage of adaptive optics is the increased sensitivity for point sources. It is simply a result of concentrating the flux of a point source in a smaller area while the background intensity (which is assumed to dominate the noise) remains constant. This provides a significant gain if one measures the flux in a suitably small aperture, the size of which is reflected directly in terms of an improved observing efficiency. Indeed, the typical resolution predicted by the various GLAO simulations presented in this contribution suggest that ~0.2" in the K-band might be achieved quite commonly. This represents a factor 2–3 improvement in the FWHM of the PSF, and hence leads to an increase by at least a factor 2 in the flux measured within a 0.25"x0.25" box (equivalent to 2x2 small pixels on LUCIFER). This can be considered either as enabling one to reach about one magnitude deeper than would otherwise be possible; or as a large improvement in observing speed.

One can calculate the gain in observing efficiency that the PSF enhancement will yield. Assuming one is in the background limited regime, then for a fixed source flux, the signal-to-noise *S/N* scales as

$$S/N \propto \frac{f_{ap} t}{\sqrt{d_{ap}^2 t}}$$

where f_{ap} is the fraction of the source flux coupled into the aperture (or slit), d_{ap} is the diameter of the aperture, and t is the integration time. Rearranging this equation, one finds that to reach a constant signal-to-noise, the observing time depends on

$$t \propto \left(\frac{d_{ap}}{f_{ap}} \right)^2$$

It is reasonable to expect that for a constant f_{ap}, the chosen aperture size will be approximately proportional to the FWHM of the PSF. LGS-GLAO allows one to reduce the aperture diameter by a factor 2–3 and hence the integration time is reduced by a factor of 4–9. This is a very significant improvement in efficiency, and much of the time the gain will be even more.

For compact sources, the signal-to-noise estimations given above do not depend on the source size or morphology. Hence they are applicable also to high redshift galaxies, since they have sizes comparable to the PSF. The calculated gain in observing speed for spectroscopy of such objects – due solely to the slit coupling efficiency – indicates that typically one might expect GLAO to yield a factor of about 5 increase in speed to reach a given signal-to-noise. And as in all cases, GLAO's unique strength comes only into play when the targets are spread across a field larger than about 20", as is expected for high redshift galaxies, allowing one to gain additionally through multiplexing.

Reducing Crowding Noise

In dense fields, crowding is the most serious limitation on the depth to which one can reach. This is a serious problem in any stellar cluster and there are many classic examples: the Galactic Centre, the Arches Cluster, 30 Doradus in the LMC, NGC 3603, Omega Centauri, etc. It also has a severe impact on studies of star clusters in nearby galaxies, such as M 33, M 82, etc. In all of these objects, the areas of interest that are crowded are much larger than the isoplanatic patch that is corrected by conventional adaptive optics, and wide field adaptive optics is the only technique that can be usefully employed.

Enhanced Spatial Resolution

Perhaps the least publicised benefit of (ground-layer) adaptive optics – and yet arguably one of its most important – is the ability, for extended sources, to 'put the flux back where it should be'. The observed surface brightness does not increase as it does for point sources; and indeed because one uses smaller pixels, an observation to reach a specified signal-to-noise may take longer. However, the gain in information content, in terms of morphology and kinematics, is crucial and cannot be achieved through any other means on ground-based telescopes.

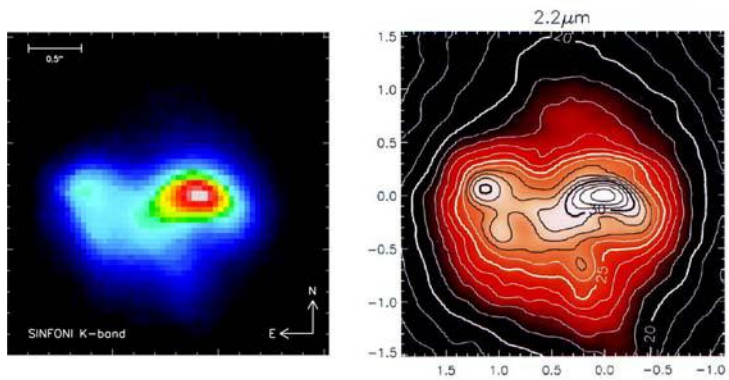

Figure 1: Images of the merging galaxy system Arp220 (taken from [9]). Adaptive optics was used to enhance the resolution in the SINFONI image (left). The GLAO system with LUCIFER is expected to provide comparable to this. Every feature in the HST/NICMOS image (right; from [10]) can also be seen in the AO data. LUCIFER will provide this resolution over a 4arcmin field of view, and yield much richer data due to the spectroscopic capability.

An example is the comparison given in Figure 1 of a SINFONI adaptive optics image to one from HST/NICMOS. The AO data were taken with a laser guide star, but without using a tip-tilt star, and yield a ~0.2" resolution. In this respect the SINFONI image is comparable to what one might expect from the GLAO system with LUCIFER. The images are of the prototypical merging galaxy system Arp220, whose progenitor nuclei are separated by only 0.9" (400pc). This merger is in its very late phases, and high spatial resolution is mandatory to see what is going on in the central regions. This example shows very clearly that adaptive optics, even if not reaching the diffraction limit, can still provide valuable resolution enhancement – indeed every feature in the HST/NICMOS image of Arp220 can also be seen in the adaptive optics enhanced image. Moreover, not only will GLAO with LUCIFER yield resolution comparable to HST/NICMOS but it will be able to do so over a 4arcmin field of view, and also provide much richer data through the ability to perform spectroscopy and hence trace the distribution and kinematics of both stars and excited gas.

3. PERFORMANCE ESTIMATION OF THE LGS GLAO SYSTEM

Within the study phase of the LBT Laser AO system the expected performance of the ground layer correction has been modelled. The basis of the simulations have been formed by SCIDAR Cn2 measurements carried out on mount Graham [11][12], reflecting a variety of seeing conditions and turbulence distributions in the atmosphere. With three independent models of the expected GLAO performance, taking different guide stars geometries, assumptions on tip-tilt, photon flux and loop bandwidth into account, we expect the simulations to well reflect the range of performances that can be achieved. The gain that can be achieved with a ground layer adaptive optics system of course depends on the fraction of turbulence which is contained in lower atmosphere. The measurements done on Mount Graham but as well on other sites [13] show that in a lot of observed cases 50% or more of the turbulence power is contained in the first kilometres above ground. Modelling the adaptive optics performance for 'good', 'median and 'bad conditions' results in an achievable gain in FWHM of a factor 2-3 in all cases. Figure 2 summarizes all performance estimates that have been made in a single plot. Regardless of the guide star geometry or laser gating height, all estimates are clustering in an area enclosed by the dashed lines. The solid line in Figure 2 shows a simple quadratic fit to all simulation points. The retrieved results in various simulations for the same baseline atmospheric models are well described by this trend.

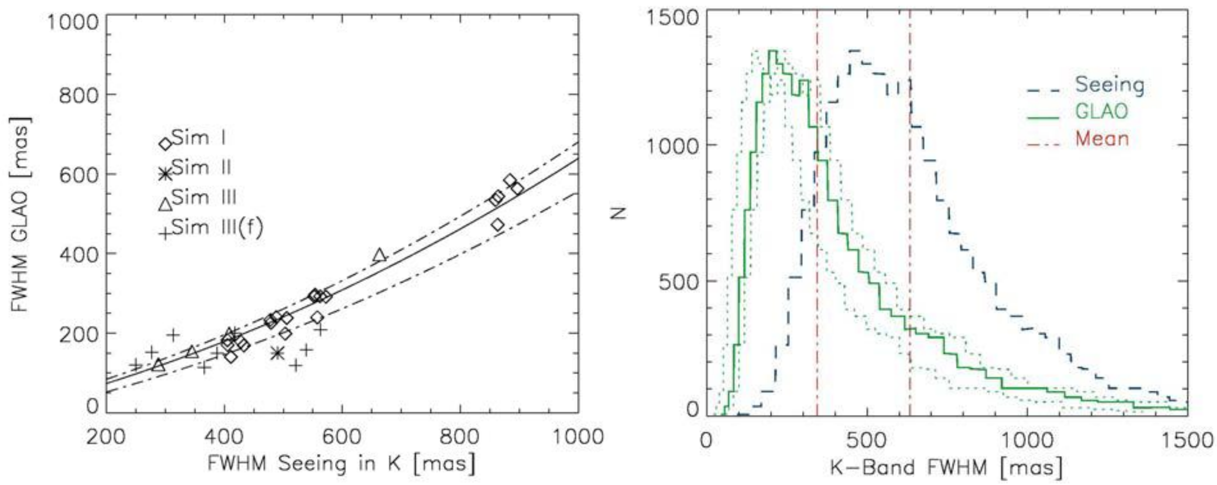

Figure 2 The simulations for the ground layer adaptive optics performance in various seeing conditions result in a range of performance estimates. To the left a summary of all simulation results is shown. For a given seeing FWHM, GLAO with laser guide stars results in a reduced PSF size. Applying the derived reduction in image PSF size to a seeing statistics as derived at the MMT, a probability distribution results, as shown in green. At the mean of the distribution the FWHM is reduced with GLAO from 0.63 to 0.34 in K-band. The dotted lines denote the range of results that have been obtained in the simulations.

Consequently one can convert the retrieved performance into a statistical view of the site. This results in the right plot of Figure 2. Taking the known seeing probability distribution from the MMT shown in blue, this distribution shifts to the left with the usage of the laser guided GLAO system. The mean K-band seeing of 0.63 arcsec is converted into a mean of 0.34 arcsec. In other words, when observing with the laser guided GLAO system, the probability to obtain a PSF size below ~0.3 arcsec is 50%.

4. THE LBT LASER SYSTEM

During a study phase the LBT Laser consortium has looked into the various possibilities for the implementation and technical realization of laser guided adaptive optics. With the prime goals of the laser system for LBT in mind, driven by the scientific goals a solution has been found that allows for promptly implementation of a ground layer correction and ensures viable upgrade paths to diffraction limited operation. The main drivers which have lead to the choices made are:

- The wide field capabilities of LUCIFER MOS and imaging, leading to unique observations when combined with GLAO.
- The need for a reliable and low maintenance system, minimizing the technical risk and changes to existing telescope systems.
- The goal to implement a GLAO system within a reasonable timescale.
- The inclusion of possible upgrade paths towards a diffraction limited operation.
- The aim to keep the AO system working significantly above median atmospheric conditions.

Guide stars created in the earth's sodium layer at 95km height are nowadays used at several 8m class observatories, like the Keck, VLT, Gemini or Subaru telescopes. Undoubtedly the choice of a laser guide star placed at large distance above the telescope has the advantage of a lower cone effect contribution to the wavefront errors. While we aim for a ground layer correction with multiple stars the cone effect error plays a less important role. Arguments like field homogeneity do have a much stronger impact on wide field observations. Thus both possibilities, guiding on multiple Rayleigh stars and guiding on multiple Sodium stars can be regarded as equivalent in possible performance for a ground layer correction system. The choice made towards a Rayleigh guided facility is basically driven by technical arguments. As of today Sodium line lasers are fully custom made. No off-the shelf solution is easily available. While this would not be an argument on its own, the handling of those lasers is still complicated, requiring a high level of staffing at the observatory.

Additionally the laser power requirements for the creation of multiple guide stars above the two eyes of the LBT are quite high. Assuming a typical 10W per beacon which is required for sufficient signal to noise and three to four guide stars per LBT eye, the total laser power required amounts to ~80W. An implementation of such a system is quite costly compared to a solution relying on Rayleigh lasers. Lasers for Rayleigh guiding are available as industrial proven units from several companies at reasonable cost, the choice was made towards this solution.

A major requirement to the system from the science cases is the need for a uniform PSF across the field. As can be seen in typical adaptive optics observations with single guide stars, the angular anisoplanatism will cause a major degradation of the image off-axis. The variation of the PSF size across the field strongly limits the scientific usefulness. Overcoming this limit for larger fields leads to the choice of multiple guide stars placed off-axis.

Having made above mentioned choices, the design of the laser and wavefront sensing facility is straight forward. A constellation of short wavelength pulsed laser beams is broadcasted from behind each of the LBT secondaries to the sky. Detection of the Rayleigh scattered light from a certain height in the atmosphere will be achieved by switching an optical gate in front of the detector after twice the appropriate time of flight. An overview of the system is shown in Figure 3 for one eye of the LBT. The system for the second eye is basically a clone of the one described, apart from system level hardware. Starting from the generation of the laser light, a set of laser heads in a stiff frame is mounted to the telescope. From the exit of the laser heads the light passes a pre-expander and polarization adaptors. A periscope assembly will bring the beams onto the launch telescope pupil, allows to steer the constellation diameter and controls the beacon position on the wavefront sensors.

On the wavefront sensor side the light from the multiple beacons will be picked up in front of the scientific instrument and is folded into the sensor. Inside the sensor a collimator and periscope is passed before a Pockels cell assembly. After that the light is send via collimation optics onto a lenslet array and a single detector, forming together a Shack-Hartmann sensor. In a nutshell the LBT laser guide star system consists of:

- A constellation of three Rayleigh guide stars per LBT eye
- One laser per beacon
- Approximately 15W laser power per beam at ~10kHz repetition rate
- A launch system with variable constellation diameter
- A wavefront sensor solution that detects the Rayleigh beacons with Pockels cell gating on a Shack-Hartmann sensor

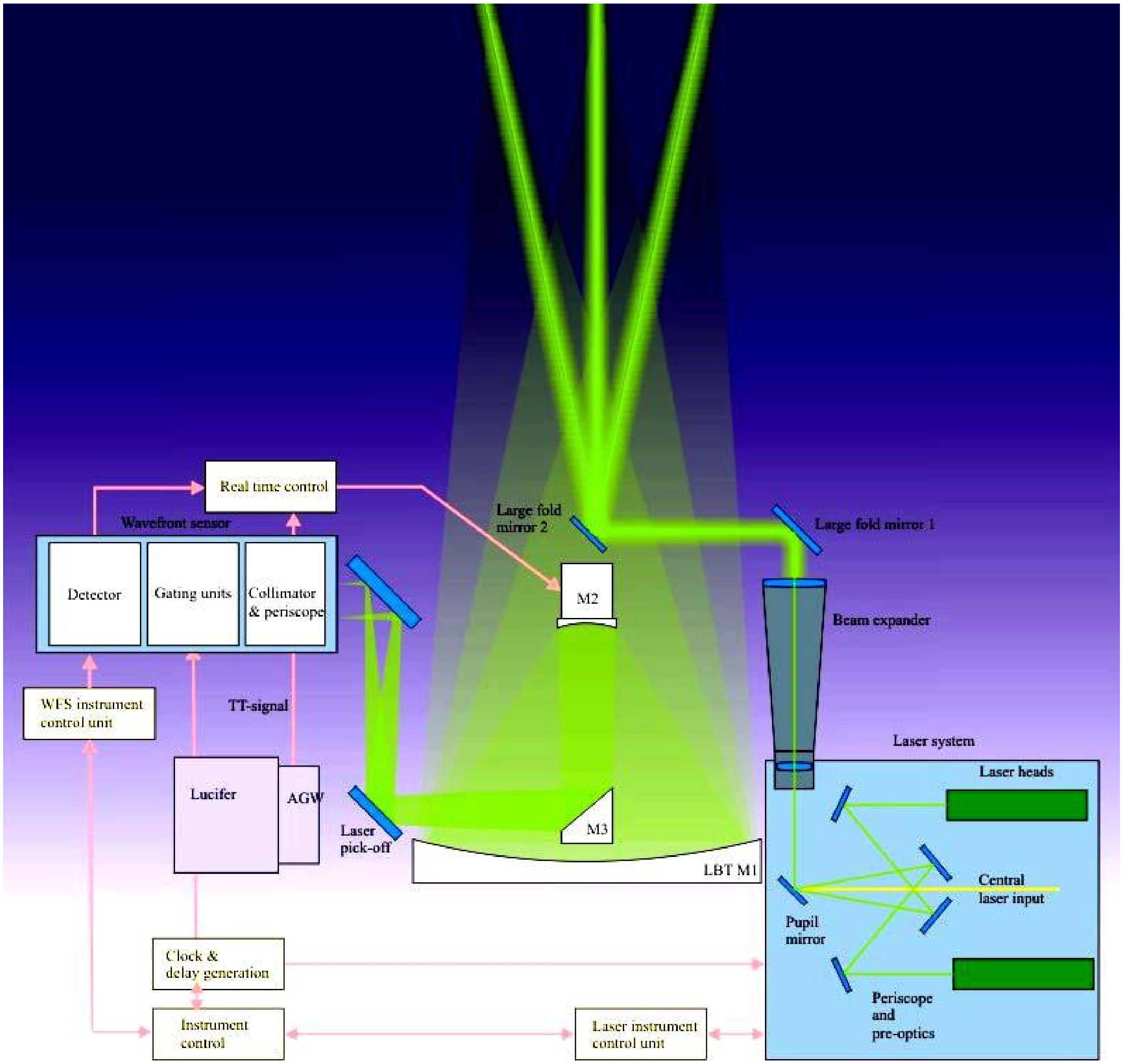

Figure 3 Scheme of the LBT laser system for ground layer adaptive optics correction. Shown here is the scheme for one eye of the telescope, the system for the second eye is basically the clone of the one shown. The facility can roughly be divided into the laser units, the launch system and the wavefront sensors. The laser system contains the laser heads, beam steering capabilities to change the constellation diameter, a central sodium laser input, beam diagnostics and all facility devices to operate it. The launch system consists of a beam expander telescope and large fold mirrors to direct the beams onto the axis of the main telescope. The wavefront sensor contains collimators and a periscope, optical light switches and a detector to register the wavefronts from the multiple laser stars and sent the control signals to the DM. A central clock and delay generator controls the overall timing.

5. LASER AND LAUNCH SYSTEM

The laser system consists of a Rayleigh guide star facility, providing multiple guide stars for each eye of the telescope. The concept of guiding on a range gated light pulse already has been used in quite some facilities. Even the earliest of laser guided adaptive optics systems [16] have been using pulsed lasers to generate an artificial star above the telescope. Nowadays astronomical adaptive optics systems make use of Rayleigh guiding again, like the GLAS facility at WHT [14], the MMT [2] and the SOAR [15] telescope. The system foreseen at the LBT will expand the capabilities of existing systems towards a multiple guide star facility.

In order to generate the multiple guide stars above the telescope, two approaches can be used: Either a single laser is split by a holographic grating, like done at the MMT, or multiple lasers are combined in a single beam expander. For the LBT we foresee the later possibility allowing for highest available power per beacon. As well the position of the individual stars can easily be steered independently, correcting for system flexure and atmospheric uplink tip-tilt.

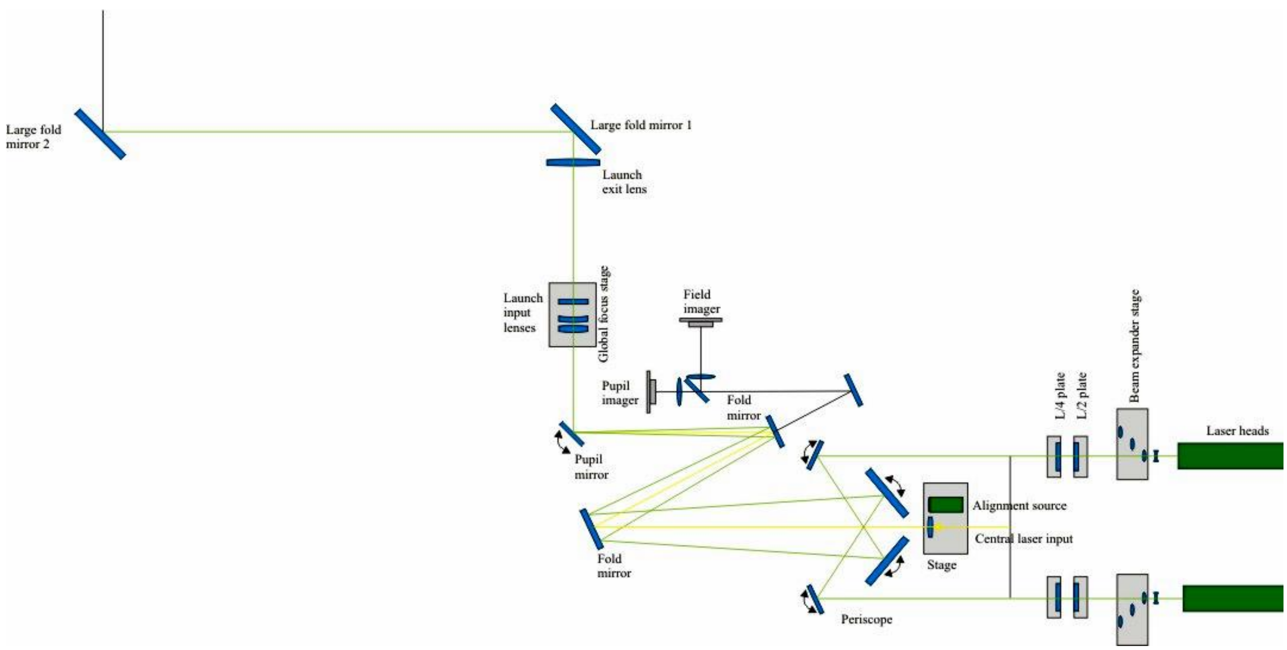

Figure 4 Scheme of the laser and launch system for the LBT. Shown is one of the units, containing lasers and beam transport optics for one of the LBT eyes. The laser system contains the lasers heads (two are shown) an exchangeable pre-expander optics, polarization optics and a periscope to change the constellation diameter. At a pupil mirror the individual laser beams are joined before entering the launch beam expander. Light leaking through the pupil mirror will be used for online diagnostics of the beam positions and pupil positions. The beam expander widens the beam to the desired diameter. Two large fold mirrors are present, one to direct the beams behind the secondary of the LBT, and one to finally send them to sky.

An overview of the planned laser and launch facility is given in figure Figure 4. The facility contains the ‘laser units’ and a beam expansion telescope per eye of the LBT. The laser units consist of the q-switched laser heads, fore optics to adopt the required beam size and polarization direction in front of the launch telescope. A periscope assembly steers the beam direction onto a common pupil mirror. With this assembly the pointing direction and the constellation diameter are adjustable. Those laser units will be contained in an enclosure and mounted stiffly to the bottom of the LBT structure. At this location free space is available to integrate a laser platform, holding the laser units, all electronics and chillers that are required to operate the system. After the pupil mirror where the individual laser beams join, a refractive beam expander widens the diameter of the lasers to 50cm before the beam is sent to behind the secondary of the LBT where a flat fold mirror directs them to sky. Due to the space available at the LBT the beam expander can be mounted directly into the structure of the telescope, allowing a long focal ratio for the telescope. A CAD view of the planned integration into the LBT is shown in Figure 5.

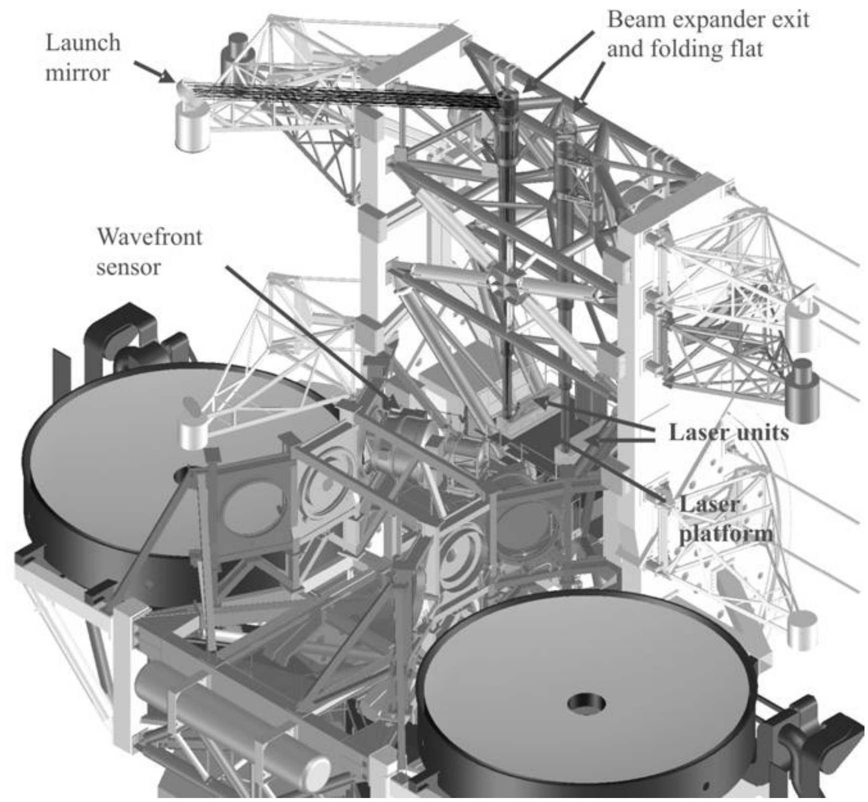

Figure 5 Integration of the laser system in the LBT telescope. Within the structure of the telescope a laser platform holds the two laser units and the electronics hardware. The expansion telescope has the bottom optics mounted at the laser unit level, and a large lens fixed to the upper structure of LBT. The laser beams are fully enclosed up the top, before traveling in free air to the flat launch mirror behind the secondary.

The specifications for the laser system are driven by the number of photons that have to be detected on the wavefront sensor, the constellation diameter on the sky and the anticipated spot size on the wavefront sensor. Others, which are already built into the system, are given by the upgrade path possibilities: Variation of the constellation diameter, repetition rate and inclusion of a central laser input for a sodium line laser. The required laser power per beacon is derived with using the known Rayleigh scattering coefficients and LIDAR equation, leading to the photon number that is expected per laser pulse and sub-aperture of the wavefront sensor.

$$N_{ph} = \eta_{rt} \frac{ED^2 \rho(H) \frac{d\sigma}{d\Omega} \Delta H}{N^2 \gamma H^2}$$

With E being the energy of the laser pulse, γ the energy of one photon, ρ(H) the number density of the molecules, H the scattering altitude, D the diameter of the telescope, N the linear number of subapertures across the aperture and ΔH the length over which the scattering is sampled. η_{rt} denotes an overall transmission efficiency from laser exit to the wavefront sensor detector, including quantum efficiency. Putting these numbers in a table to get an estimate of the expected photon numbers, using: 532nm, a 2.4mJ pulse energy, 5kHz repetition rate and 1kHz detector framerate on a 16x16 Shack Hartmann array yields:

Table 1: Photon numbers for various gating heights and ranges.

Gating height [km]	8	10	12	15	20	25	30
Range gate[m]	80	100	120	150	200	250	300
N-photons	1140	700	446	240	93	38	16

The calculated ~400 photons per frame and sub-aperture result in a signal to noise ratio well sufficient to allow for accurate centroiding of the Shack-Hartmann spots on the detector. Nevertheless variable transparency conditions in the atmosphere and degradation of optics exposed to ambient might lower this number. An additional contingency can be gained with extending the range gate to larger values, until the elongation of the spots in the outer sub-apertures becomes unacceptable. The main specifications for the individual laser heads drawn from the photon numbers and system requirements are:

- Repetition rate ~5-10 kHz
- Average power output >12W
- M-squared factor <1.3
- Wavelength 515, 527, 532 nm possible

While the average power output and the M^2 factor are mandatory specifications, the repetition rate can be varied in quite some range. As well the wavelength of the laser does not play a major role, since the scattering will not be too strongly influenced by a change in wavelength of ~50nm. With those specifications a variety of lasers are available from commercial suppliers with Nd:YAG, Nd:YLF or Yb:disc as gain medium. Typically the average output power of commercially available Q-switched YAG lasers reaches 12W at 5kHz and 15W at 10kHz today.

6. WAVEFRONT SENSORS

The wavefront sensor units for the GLAO system have to detect the multi-beacon light from the 12km altitude beacons. The optical design is arranged such, that a single CCD and a single lenslet array can be used to provide three to four Shack-Hartmann sensors at the same time. In the foreseen optical configuration each of the SH sensors splits the pupil with the lenslet array in the required amount of sub-apertures. While the exact pupil sampling is subject to further optimization, we expect a sampling above 14x14 lenslets over the telescope pupil to be sufficient for the degree of required correction. A detailed description of the wavefront sensor arrangement is given in paper 7015-188, this proceedings. To allow a single CCD to detect the multiple beacons the widely spaced stars in the finite image plane have to be compressed by periscopes and the CCD must provide enough pixel to sample all the pupils. A preliminary opto-mechanical layout is shown in Figure 6.

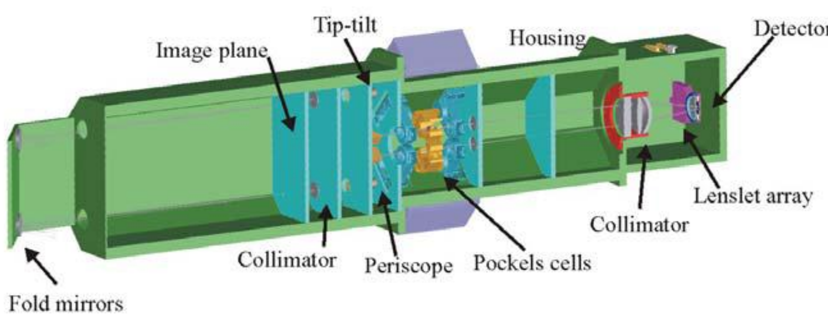

Figure 6 A CAD view of the WFS opto-mechanics and enclosure. The yellow parts represent the Pockels cell units bracketed between the polarizer filters (in blue in the drawing), mentioned in paragraph 6.1. The red mount holds the collimator and the purple one holds the SH lenslet.

6.1 Gating

As the laser pulse is traveling upwards through atmosphere, it constantly scatters at the air molecules. The required gating height therefore has to be selected by a fast shutter. For this task we foresee a Pockels cell arrangement to be placed in the collimated beam before the detector. Similar arrangements are in use at the SOR, WHT and planned for the SOAR telescopes. As this task and the knowledge of the switch behavior is crucial for the AO performance a test setup is already in operation, consisting of a single pass BBO electro-optic crystal and a high voltage driver. With this test setup we are able to derive the contrast of the cell under realistic conditions of diverging beams and measure the pupil illumination in dependence of the pulse height in the atmosphere. The measured values will be a valuable input for the detailed performance model of the adaptive optics correction. An image of the test crystal in its housing and the switching behavior is shown in Figure 7.

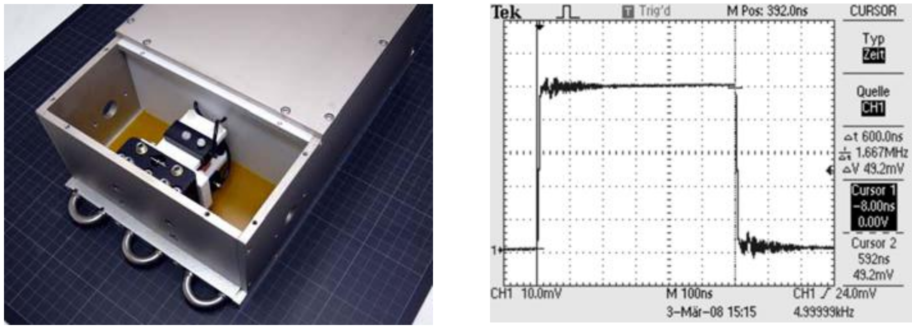

Figure 7: Left: The integrated BBO test crystal into the housing close to the HV driver. Right: Oscilloscope trace of the optical transmission when switching the cell. Opposite to other usual electro-optic crystals, BBO basically shows no piezoelectric ringing, resulting in a clean controlled light gate. The typical risetime of the gate is below 10ns

6.2 Detectors

The basic requirements for the CCD detectors are quite similar to most adaptive optic systems and are drawn from the anticipated sampling of the wavefronts over the pupil, the foreseen bandwidth and the acceptable noise level. As pointed out earlier a single detector is aimed for the measurements of all guide stars, facilitating the electronics and optical system. Therefore the size of the detector has to be approximately four times larger as for other AO systems, arriving at a 256x256 pixel demand. Bearing in mind that we have a strong goal to operate significantly above median atmospheric conditions and making full use of the high speed of the deformable secondary mirror, the required framerate is aimed to be ~1 kHz. A CCD fulfilling the requirements is developed at the MPI semiconductor lab and is planed for the laser wavefront sensing. These devices with an image area of 264 x 264 pixels and 48umx48 um pixel-size were designed for optical applications with frame rates up to 1000 frames per second. The devices, sensitive from the UV to the near IR region, are backside illuminated and sensitive over their full thickness of 450um. They have a peak quantum efficiency (QE) of nearly 100%. High frame rates are possible by split-frame transfer concept and column-parallel readout. The readout noise is below 3 electrons rms [20].

7. FROM GLAO TO DIFFRACTION LIMITED OPERATION

As outlined above the scientific gain expected from the GLAO system in combination with the particular characteristic of the LBT instrumentation, like the adaptive secondary and the wide field of view of LUCIFER, led to highest priority for a Rayleigh based ground layer system. Nevertheless several important science cases require a system able to achieve diffraction limited images in H and K band, like achieved with a single powerful sodium laser. Making use of the first light implementation of a Rayleigh guided ground layer correction, leads to interesting combinations with a second step sodium layer laser upgrade [21][22] or dynamically refocused Rayleigh lasers. A sketch of the hybrid laser guiding is shown in Figure 8. The turbulence above ground is sampled at high spatial and temporal resolution matched to the small r0 values in those layers. The additional central sodium laser fulfills the purpose to measure the high altitude turbulence which is completely un-sampled by the Rayleigh stars. With having available guide stars at different height a wide range of possible correction schemes is possible with such a combination, including tomographic reconstruction and layer oriented arrangements. A central point is the consideration that the high altitude turbulent layers leave a residual wavefront error corresponding to effective large r0 values. Thus the sampling on the wavefront error can be done with much larger sub-apertures. As a simple consideration, when moving from a typical 15x15 subaperture geometry that is required for full atmosphere sampling to a system that needs to correct 20 modes of residual high layer error, the area of each subaperture increases by a factor ~10. The required laser power decreases by the same amount, thus reducing the typical need of 15W of a single sodium system to ~2W for the hybrid combination. Lasers at this power level are much easier to handle and to implement.

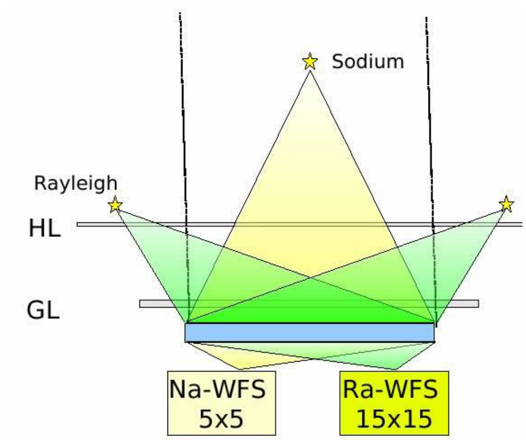

Figure 8 A sketch of the arrangement of the proposed sources for the upgrade of the GLAO system. Adding a central low power sodium laser to the firstly implemented Rayleigh guide stars allows to detect the high layer turbulence at lower spatial sampling.

An interesting combination is as well gained when using instead of the central sodium a natural guide star to sample the high layer contribution. Operating the ground layer adaptive optics in parallel with this natural guide star decreases as well the required sub-apertures on the natural star, which results in a gain in limiting magnitude by a factor of ~2 for the NGS AO system.

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