Calibration strategy and optics for ARGOS at the LBT

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ABSTRACT

Effective calibration procedures play an important role for the efficiency and performance of astronomical instrumentation. We report on the calibration scheme for ARGOS, the Laser Guide Star (LGS) facility at the LBT. An artificial light source is used to feign the real laser beacons and perform extensive testing of the system, independent of the time of day and weather conditions, thereby greatly enhancing the time available for engineering. Fibre optics and computer generated holograms (CGHs) are used to generate the necessary wavefront. We present the optomechanical design, and discuss the expected accuracy, as well as tolerances in assembly and alignment.

Keywords: Wavefront sensor calibration, AO systems, Laser guide stars

1. INTRODUCTION

The LBT consists of two identical 8.4 m telescopes, sharing the same mount. The telescope has been designed with integrated AO capabilities in mind. All adaptive optics operations make use of an adaptive secondary mirror (ASM) in a Gregorian configuration. Each ASM has 672 voice-coil actuators on a thin shell of 910 mm diameter. The focal ratio in the prime focus is f/1.1[1].

The AO facility has just recently seen first light[2], using pyramid wavefront sensors on natural guide stars. To enhance sky coverage and therefore the efficiency of the system, the integration of a laser guide star facility, ARGOS, is underway[3]. ARGOS will make use of a constellation of three Rayleigh laser beacons above each eye of LBT to provide AO correction over a wide field of view (FOV) based on a ground layer AO (GLAO) scheme. With six laser guide stars altogether, and the deformable mirror as integral part of the telescope structure, ARGOS is a complex system that cannot be fully tested in the lab before being commissioned at the telescope. We therefore deemed it necessary to have an accurate means to calibrate and test the system with artificial light sources during the day, and hence minimize the amount of night hours needed to commission the system. The calibration system also permits recalibration during regular operations.

A scheme adopted by many AO facilities is to use an artificial light source in an intermediary focus before the deformable mirror, that imitates the guide star and hence allows the wavefront sensors to be run at any time[4,5]. We follow this idea, but face the additional problems of having to install such a light source in front of the secondary mirror, and not on an optical bench. Furthermore, the images of the laser beacons that have to be replicated suffer from substantial aberrations from the primary mirror due to their position 2 arcminutes off axis. The parabolic primary introduces more than 200 waves of coma at the laser wavelength of 532 nm. To enable a realistic calibration, the laser beacons' wavefront should be matched to better than lambda/5 rms. We designed a hybrid objective, comprising conventional lenses and a computer generated hologram (CGH), to reimage an optical fibre and thereby create the desired wavefront with the above precision. The front surface of the lens system is a concave ellipse, equipped with a dichroic coating. It is used in reflection to simultaneously generate a diffraction-limited on-axis spot on the science camera to serve as a truth sensor, and doubles as an alignment aid to position the unit with respect to the telescope. A scheme of the lightpath is shown in Figure 1.
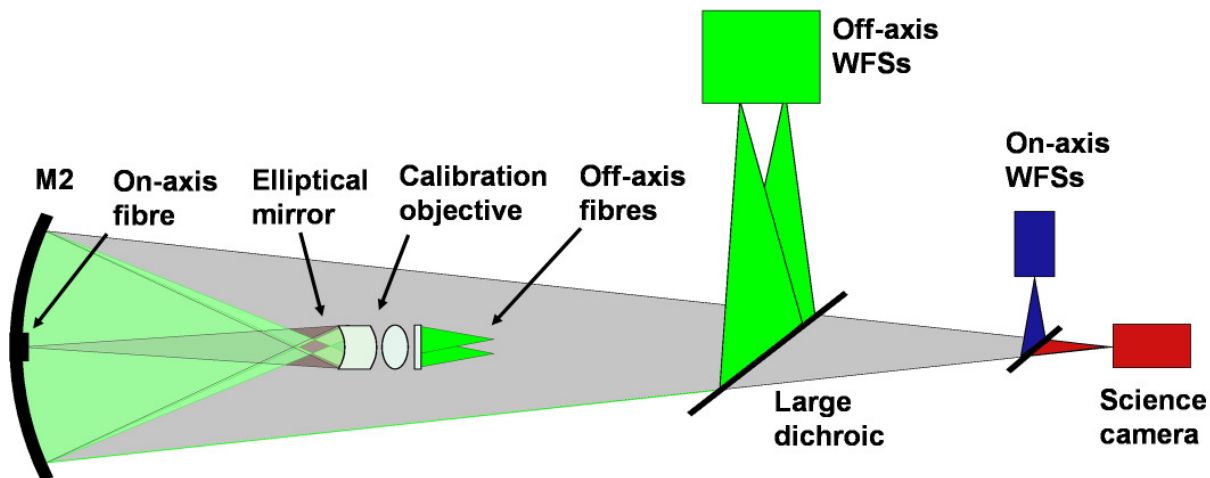
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Figure 1: Schematic of the lightpath of the calibration unit. Off axis calibration spots are generated by a calibration objective in transmission, and redirected to the wavefront sensors by a large dichroic mirror. Simultaneously, the light form a fibre in the central bore of the secondary mirror is reflected off the front surface of the calibration objective, and generates a diffraction limited spot on the science camera and the on axis wavefront sensor.

2. OPTICAL DESIGN

The lens design forming the calibration unit has to have various properties. We wanted to remove most of the necessary optical power from the CGH. The objective has to match the secondary mirror focal ratio to the numerical aperture of three multimode fibres that serve as light sources. We use multimode fibres to simulate the finite extension of the beacons on sky. To avoid mixed orders originating at the hologram substrate, the three holograms for the three beacons should not overlap. The lens system has to provide a plane in which to mount the CGH where the beams do not overlap and the optimal illumination is homogeneous. Ideally, the CGH should be located between the lens system and the fibres to allow for the most precise registration of the fibres with respect to the hologram substrate.

As outlined above, the front surface of the objective is required to be a prolate rotation ellipsoid with one focal point on the prime focus of the telescope and the other focal point on the tip of a fibre mounted in the secondary mirror's vertex. Outer constraints are the allowable envelope of 80 millimetres diameter, and the desire to operate the unit across a wide temperature range (-20°C to 20° C).

2.1 Lens elements

We found a solution comprising four lenses with moderate lens radii and all-spherical surfaces, apart from the ellipsoidal front surface. The material of all the lenses is Fused Silica to minimize temperature sensitivity. The lens radii are fitted to a testplate inventory, reducing cost and at the same time facilitating the highest precision manufacturing. The resulting design meets all the requirements. A crosscut of the objective is shown in Figure 2. The components fit into a lens barrel with 80 mm diameter and about 180 mm length. All the mechanical components are machined from Invar, which is well matched to the low coefficient of thermal expansion (CTE) of fused silica. The differential shrinkage between the lenses and the Invar lens fits amounts to only 2.5 microns across the whole temperature range.

2.2 Computer generated hologram

The CGH is placed in front of the three multimode fibres and transforms their spherical output to the ideal wavefront shape in the respective plane. Three identical CGHs are written on the same Fused Silica substrate, rotated by 120 degrees (see Figure 3). They are photolithographically manufactured using a laser writer, which is rotating the substrate about its centre. A fortunate side effect is the fact that this technique automatically achieves a very good centration of the CGH pattern on the substrate. Additional alignment holograms on the unused area of the substrate allow for easier assembly of the objective, and aid the alignment on the telescope by creating reference spots[6].
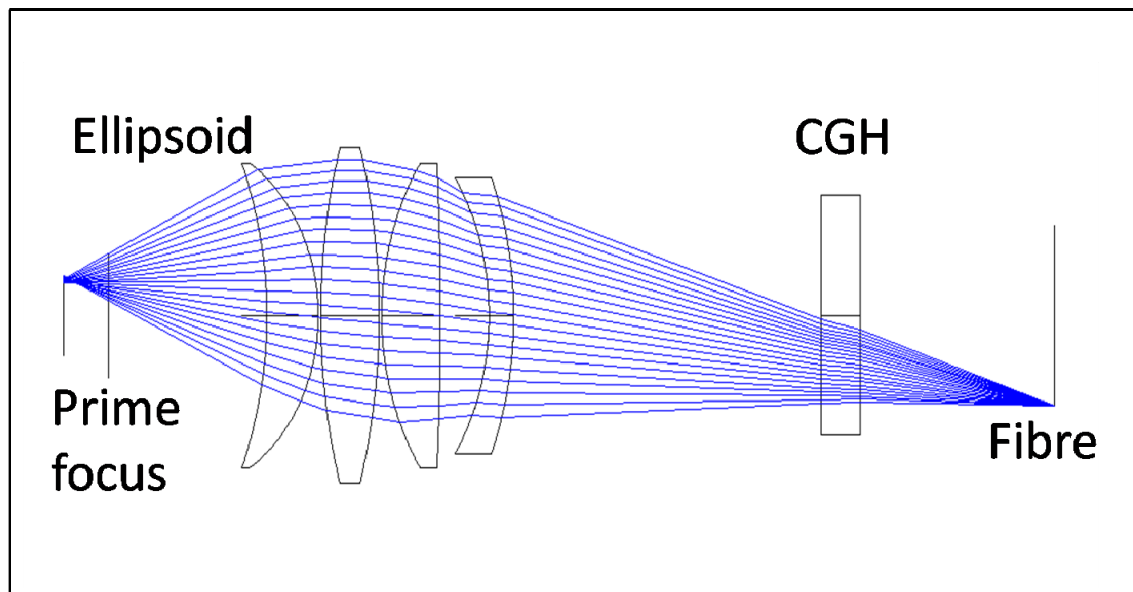
Figure 2: Crosscut of the objective, imaging one of three fibres into the prime focus of the telescope.
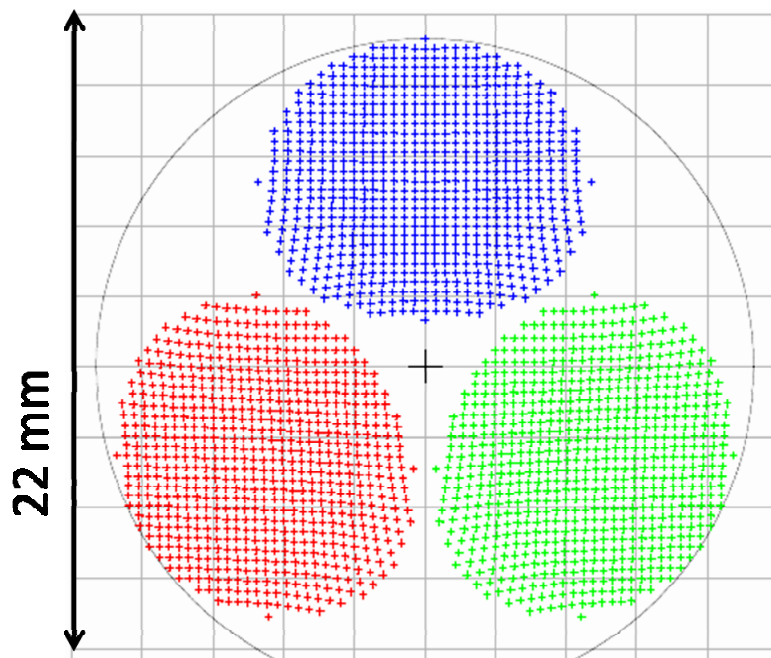

Figure 3: Footprint of the three beam shaping holograms on one common substrate.

2.3 Tolerances

To achieve the necessary specifications, the assembly must meet tight tolerances. We compensate for differences with the CGH for rotationally symmetric deviations from the ideal values, by obtaining and measuring the lenses and lens barrel first, and reoptimizing the CGH prescription. We estimated the centring tolerances using a thorough tolerance analysis. Investigating the state of manufacturing capabilities showed they can be met with precision lenses and a monolithic lens barrel made from Invar, without the need to adjust the radial positions of the components. This makes for a simple mechanical design that is thermally stable and insensitive to handling. Table 1 summarizes the tolerances.

Table 1: Tolerances on optical components, assembly and alignment.

Parameter	Tolerance
Components	
Radius	2 fringes of power
Surface figure	¼ fringe
Centre thickness	0.1 mm
Wedge	0.3 arcmin
Assembly	
Airgap thicknesses	0.01 mm
Airgap wedges	0.005 mm
Centring	0.01 mm
Alignment	
Δr (radial displacement)	0.02 micron
$\Delta\theta$ (tilt)	3 arcminutes
Δz (axial displacement)	0.005 mm

A thorough analysis based on Monte Carlo simulations of the lens system allowed us to include all the tolerances on the lens parameters, the assembly and the alignment for an estimate of the resulting deviation of the wavefront from its ideal shape. The result of the Monte Carlo analysis of the calibration unit assuming the tolerances listed above leads to the spot diagram shown in Fig 4. For comparison, the spot diagram of a point source at 12 km altitude, at the location of the real laser beacons, is shown too. The spot and the achieved wavefront meet our requirements.
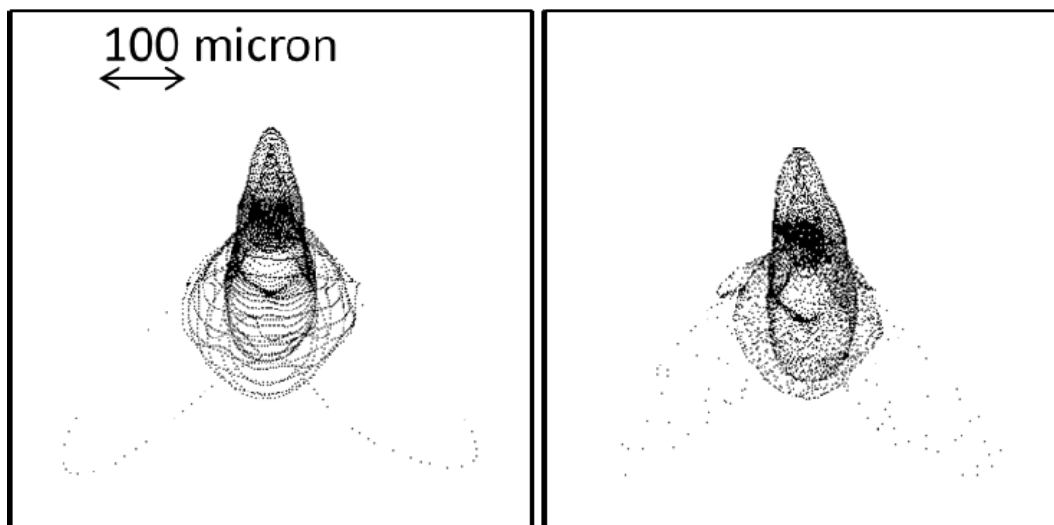

Figure 4: Spot diagrams of the calibration unit as generated in the secondary focal plane. On the left, the ideal design, on the right, the spot after applying all tolerances as in Table 1.

3. CONCLUSIONS

We described a calibration unit, providing three calibration spots imitating the images of the off-axis Rayleigh beacons of the ARGOS facility. This calibration unit is the first such system to illuminate the adaptive secondary mirror. It allows for the wavefront sensors, as well as the full control loop of the AO system, to be operated at any time for testing and calibration purposes. Additionally, a diffraction-limited spot is generated on-axis to illuminate the science camera and serve as a truth sensor to check the performance of the system. The optical design uses only fused silica components. To shape the wavefront to the ideal form, the objective comprises four lenses and one computer generated hologram, a novelty in this context.

We have finished the design phase of the calibration unit and are in the process of procuring the components. We have received interesting bids, and expect integration and testing to start later this year. The calibration unit will be a valuable addition to the AO facility at LBT.

ACKNOWLEDGEMENTS

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