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WIVERN, a laboratory experiment for testing novel laser-based wavefront sensing techniques

Nazim Ali Bharmal[a], David Bramall[a], Ariadna Calcines[a], Timothy Morris[a], Jürgen Schmoll[a], and Lazar Staykov[a]

[a]Centre for Advanced Instrumentation, Department of Physics, Durham University, UK

ABSTRACT

WIVERN is a testbed for laboratory experiments in laser-based wavefront sensing. It emulates laser uplink from a 4 m telescope with 1.6 arcsec seeing and laser back-scattering from up to 20 km. Currently there are three current wavefront sensing capabilities. The first two are from a wide-field of view (1.0 arcmin) Shack Hartmann wavefront sensor observing a constellation of point sources at infinity (reference targets, star-oriented wavefront sensing), or an image from emulated back-scattering (wide-field correlation wavefront sensing). The third is based on the PPPP concept. Other sub-systems are laser projection replicating a pupil launch, a 7x7 pupil-conjugate deformable mirror (DM), and a wide-field camera for PSF analysis. A 500 Hz rate accumulates sufficient data for statistical and machine-learning analysis over hour timescales. It is a compact design (2.1 m^2) with mostly commercial dioptric components. The sub-system optical interfaces are identical: a flat focal plane for easy bench reconfiguration. The end-to-end design is diffraction-limited with $\leq 1\%$ pupil distortion for wavelengths λ=633–750 nm.

Keywords: adaptive optics, guide-star lasers, laboratory

1. INTRODUCTION

WIVERN (Wide-field Investigation of Variability Estimation using Retrieval without NGS, natural guide-star) is a new experimental testbed constructed at Durham University for laboratory experiments in non-LGS (laser guide star) laser-based wavefront sensing. The rationale is that while there are significant advances in XAO,[1] it is difficult to conceive of wide-field MCAO (multi-conjugate AO) and MOAO (multi-object AO) over arcminute scales with good sky-coverage without the cost of GSLs (guide-star lasers) becoming prohibitive.[2] Therefore, CfAI has been funded to test in situ at two non-LGS concepts: correlating Shack Hartmann on back-scattered laser speckle, via Rayleigh scattering, to approximate a continuum of randomly placed guide stars, and the PPPP concept.[3] The fundamental idea behind the speckle concept is power density is diluted which permits powerful lasers without safety risks together with wavelength which is not restricted by the scattering mechanism unlike Na resonance. Meanwhile the PPPP concept has been extensively tested in simulation[3] and in the laboratory[4*] and application of machine learning leads to much improvement in SNR—lower laser power—and potentially considerably simplified implementation (single plane rather than dual plane).

WIVERN will test these concepts, and potentially others, using its open optical- and software-design. It is designed to simulate laser uplink through the atmosphere from either a 4 m or 8 m telescope with two phase screens, one ground-conjugated and the second up to 15km distant with 1.6 or 0.8 arcsec seeing. The laser uplink is reconfigured depending on the WFS concept but the common factor is an emulation of atmospheric back-scattering from up to 20 km distance. Two emulation mechanisms will be available: using fluorescence to downshift the frequency or polarization-conserving scattering,[4,5] allowing separation of the laser uplink and downlink by wavelength or polarization, respectively. To verify these concepts' measurements, a standard WIVERN capability is the Shack Hartmann WFS to measure a constellation of point sources that simulates several, conventional, star-oriented WFSs. These measurements, from each point source independently, will act as the control for the new concepts.

Send correspondence to n.a.bharmal@durham.ac.uk

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WIVERN has a design which is described as modular: the fundamental sub-system is the Exterior, containing a pupil with aberrations and a separate source of aberrations not conjugate to this pupil, point sources that act either as WFS targets or diffraction-limited targets for estimating the effect on the PSF, and a free-space region with (some sort of) back-scattering emulation, as discussed above. The output interface is compatible with all other sub-systems: a polychromatic, flat f/10.84 focal plane. These other sub-systems are a laser projection (Laser Launch) replicating a monostatic launch through the system pupil, a correction (Deformable Mirror) which is currently a 7×7 DM at a pupil conjugate, and a wide-field imaging camera (Camera) which is used for PSF analysis, and finally some type of WFS (currently, the Wide-Field Wavefront Sensor will be implemented).

WIVERN has been designed as a compact system ($2.1\,\mathrm{m}^2$) using commercial dioptric components, with sub-systems using a common focal plane-to-pupil relay if possible as part of their prescription, and we only use one type of low-cost custom singlet lens 6 times in the presented configuration. The layout allows access to many foci and one free pupil where a stop is placed. Since the sub-system optical interfaces are identical, the sub-systems can be reconfigured arbitrarily, e.g. the DM placed ahead of the laser injection for uplink compensation experiments. The final end-to-end system has diffraction-limited quality and $\leq 1\%$ pupil distortion for wavelengths between 633 and 750 nm, although the laser uplink extends down to 532 nm for fluorescence excitation for emulating 3D atmospheric back-scattering. The optical design, description of components and performance are presented in the next sections.

2. OPTICAL DESIGN

The common design consideration of WIVERN is maximum reuse of existing components and designs to reduce cost. For the optical design, commercial off-the-shelf achromatic lenses and dichroics, and flat mirrors were the prime components, with one custom singlet used six times in the optical interfaces between sub-systems to optimize optical quality. Furthermore the design inherits the heritage of two previous experiments[5,6] to develop a key focal plane-to-pupil (F2P) plane prescription that is extensively reused to provide a relay of input to output: a flat f/10.84 focal plane is the optical interface which permits sub-systems to be connected with arbitrary relationships. While we present one design of the experiment here, it would be possible to reconfigure the existing sub-system designs or introduce new sub-systems to produce different adaptive optics (AO) emulation capabilities. The sub-systems in their default configuration are now discussed, as shown in the annotated ray-trace diagram, Figure 1.

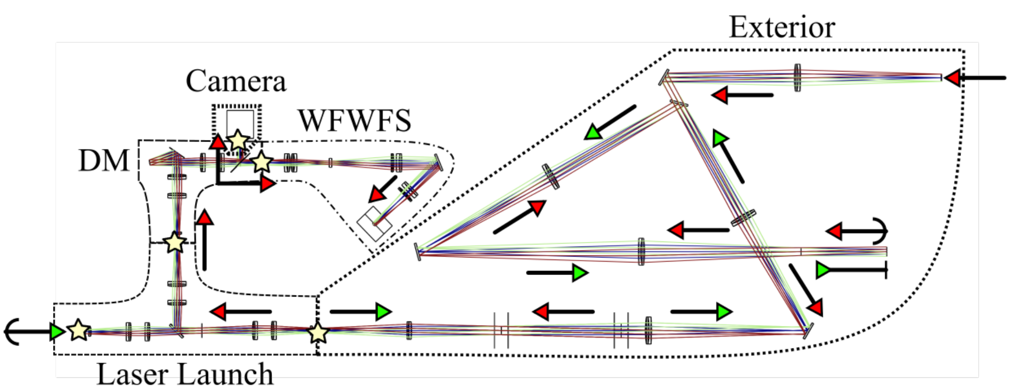

Figure 1. A Zemax ray tracing model of the initial WIVERN configuration of sub-systems. Each sub-system is delineated with a dashed line. The star symbols represent the interface focal plane, where nominally any other sub-system is optically compatible to interface. Note that the Camera and DM sub-systems overlap since they are intimately tied into each other via the dichroic. The arrows represent either wavelengths longer than 640 nm (illumination from the Exterior) or from the Laser Launch (532 nm wavelength). Note that within the exterior the 532 nm laser is down-converted to lower frequencies via a fluorescence mechanism that converts the back-scattered light into wavelengths less than 640 nm but longer than 532 nm: hence at the Laser Launch, this back-scattered light is diverted towards the DM and WFWFS sub-systems. The Camera can only see the longest wavelengths from the Exterior, produced by the diffraction-limited fiber targets. The NGS fiber targets are instead only visible by the WFWFS.

2.1 Exterior and Laser Launch sub-systems

The illumination in WIVERN is either from the Exterior sub-system with its internal illumination sources (replicating starlight), or from the Laser Launch which back-illuminates the Exterior that in turn back-scatters this input light towards the rest of the experiment (replicating GSLs, guide-star lasers). This is shown in Figure 1.

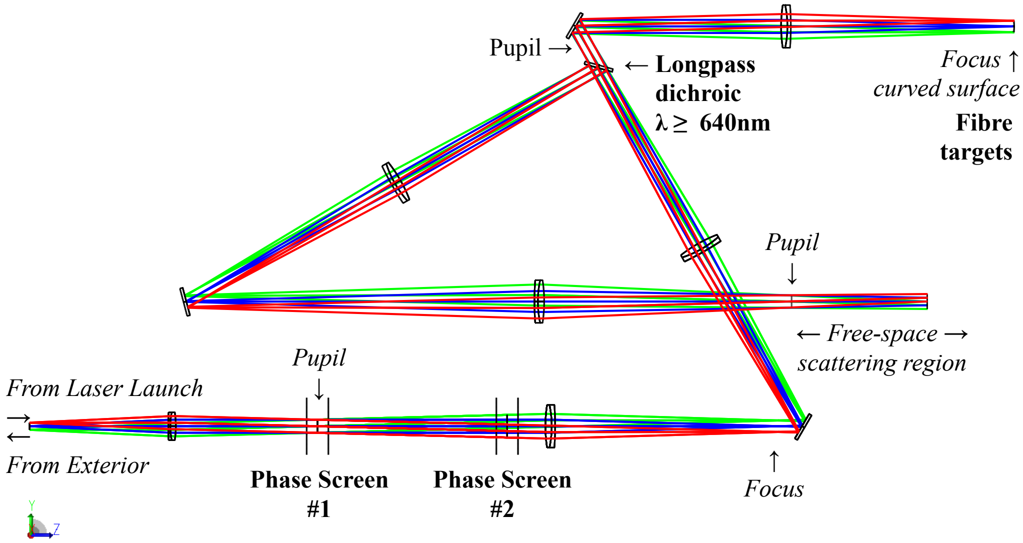

Figure 2. A Zemax ray tracing model of the Exterior sub-system. The optical interface to the other sub-systems (for input from the Laser Launch and output illumination) is at the bottom left. Two Phase Screens are shown, one at the pupil (fixed) and the other at the maximum conjugation (10 km for a 4 m pupil). The other internal focus and pupils are not used but shown to demonstrate the basic 4-f design. The longpass dichroic separates the laser launch and back-scattered fluorescence, within the free-space scattering region, from the longer wavelengths that the fiber targets produce.

Figure 3. A phase screen (grey) positioned at (left) the pupil (orange) with screen #1 Ø83mm and (right) at a finite altitude (meta-pupil) with screen #2 Ø92mm. The largest pupil size of Ø24mm is illustrated with the altitude of screen #2 at the maximum position.

The Exterior is discussed first and consists of two 4-f image relays, using Edmund Optics doublet lenses, with a principal pupil having a 23 mm diameter. At this pupil (two other conjugates exist but are not exploited) a phase screen is placed, which is used together with a second screen that is up-to 350mm distant: see the Mechanical Design section for more detail on the mounting of these screens into the Turbulence Simulator. (In passing, the pupil stop is at a conjugate pupil in the Laser Launch sub-system.) We have chosen to use custom designed phase-inducing 100m m diameter phase screens from Lexitek Inc. and by placing a fixed screen at the pupil can emulate basic concepts such as GLAO (Ground-Layer AO) with designed Fried parameter, $r_0(550\,nm) = 0.53$ mm. The second phase screen can be translated along the axis between 80 and 350 mm from the pupil, with design Fried parameter, $r_0 = 0.81$ mm. These conjugation distances translate to between 2,400 m and 10 km distance for a 4 m pupil-scaling, with the Fried parameters for each screen then corresponding to 9.2 cm and 14.0 cm respectively. This pair of screens permits the investigation of tomographic wavefront sensing experiments, as shown in Figure 3. As is common with this technology, either screen can be independently rotated, to enable a limited emulation of frozen flow by offsetting the phase screens by ≈ 59 mm to illuminate a sub-pupil off-axis. Our mechanical design also allows either to be easily removed or swapped: see later in this article.

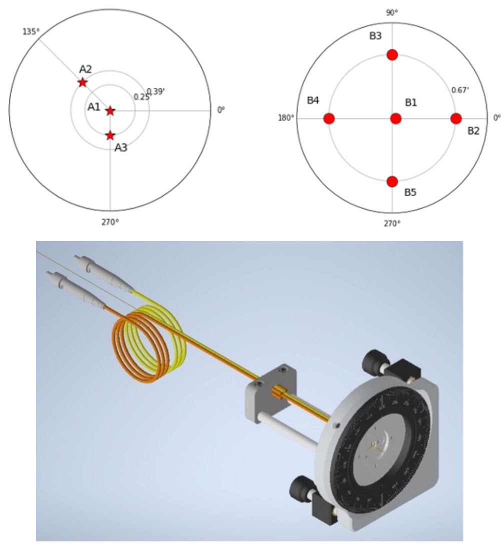

Figure 4. (Top left) Diffraction-limited and (Top right) NGS point-sources, shown diagrammatically to emphasize their radii and angles for a 4m-pupil. Note that the WFS source ‘B1’ is offset to show that it is coadjacent with diffraction-limited source ‘A1’ but not coincident—the fibers are placed side-by-side into one ferrule with a spacing no greater than 265 microns. (Bottom) A CAD rendering of the point-sources mount showing the inner stepped plate into which fibers are bonded, with the plate held in a CotS mount and strain-relief for the fibers at the rear.

Following the second phase screen, the internal focal plane is conjugate either to the point-sources or to within the free-space region for emulating back-scattering. The point-sources lie on a spherical surface with a RoC of 30.92 mm and are made up of fibers aligned to that surface, see Figure 4. Each fiber represents either NGS targets for the WFS or diffraction-limited targets for the field-imaging. After reflecting from the DM, light from the fibers is split using a dichroic; longer wavelengths than 740 nm go to the Camera and the remainder to the WFS. The WFS produces the principal measurements for WIVERN from (but not limited to) NGS point-sources and the Camera is used to study the PSF across the field using the diffraction-limited point-sources, at 750 nm, hence single-mode (SM, 4µm mode field diameter) fibers are used. The NGS point-sources are multi-mode fibers (MM, 365µm diameter) and larger by a factor of nearly 10,000 in area, which greatly improves flux but nonetheless they remain unresolved by the WFS sub-apertures, at wavelengths from 650 to 740 nm. These two types of fiber point-sources are the internal illumination mentioned earlier, and are transmitted via the phase screens, and so are necessarily aberrated at the Exterior sub-system output focus.

Meanwhile, the free-space region is where light that enters the Exterior from the Laser Launch, always from a 532nm laser which has been reflected from the point-sources light path using a dichroic for wavelengths shorter than 640nm, is allowed to freely propagate in a separate arm. In this arm, by placing one or more surfaces that can fluoresce, conjugate to distances further from the pupil than the second phase screen, we can emulate scattering in the atmosphere from pulsed, illuminating lasers whose returned light has been time-gated. See Figure 5 for an example previously used successfully by CfAI which we shall base our implementation on. The back-scattered light, downshifted in frequency, which passes back through the phase screens—which implies that

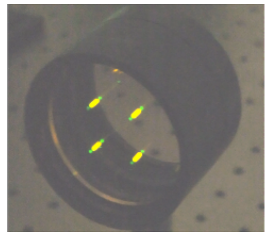

Figure 5. A previous example of a fluorescent cell being illuminated by 532 nm and having a peak re-emission wavelength of ≈ 580 nm. The illuminating laser reflection can be seen on the entrance and exit windows with the fluorescence occuring in between, where the dye is in solution, and so can be separated via a dichoric.

we can model both the uplink and downlink—has a realistic emulation of laser light behavior and ultimately leaves the Exterior.

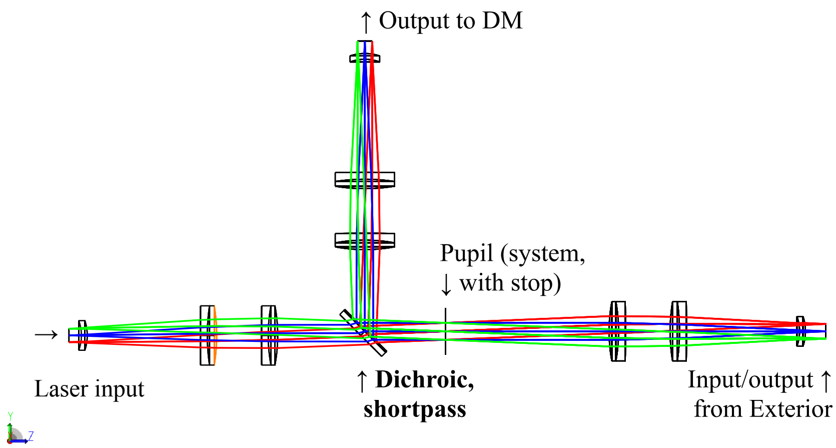

Figure 6. The Laser Launch consists of three F2P relays with an intermediate dichroic or beamsplitter. The optical interface for the inputs and outputs are therefore identical: the choice of which interface the laser is shone into is based on our chosen dichroic being shortpass.

In the Laser Launch, light from the Exterior is separated from the 532 nm input light by virtue of Exterior-origin light having a longer wavelength. This back-scattered light and that from the fiber point-sources are both transmitted onwards to be measured and then cross-compared, which is ultimately the aim of this configuration of WIVERN. The laser launch, shown in Figure 6 is either an on-axis beam, with zero or mild divergence, for the PPPP experiments, or with low spatial coherence, for the correlating Shack-Hartmann experiments. Unlike other bench experiments,[5] this version of WIVERN does not emulate LGS.

For the optical design of the Laser Launch and other sub-systems that use the F2P relay, a great challenge was to design a 1:1 telecentric relay for a large field of view with a diameter of 5.44° offering near diffraction-limited quality over our visible bandwidth using commercial lenses. Achromatic lenses from Thorlabs were used to achieve diffraction-limited optical quality following the approach in Figure 7: two different doublets are used to generate a F2P relay. This is replicated in a layout that is symmetric with respect to the pupil, producing a focus-to-focus relay.

A low-cost custom singlet lens is used close to each focus (object and image), which improves the final optical

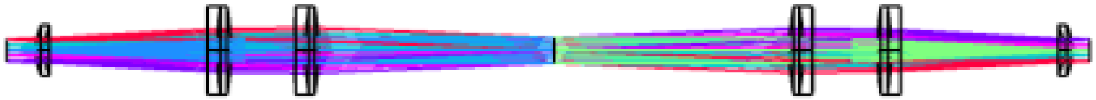

Figure 7. Layout of a telecentric 1:1 relay, made of two F2P designs back-to-back with a field of view of 5.44° diameter and diffraction-limited optical quality. The layout is symmetric with respect to the intermediate pupil image, the flat plane in the centre.

quality. This design is telecentric and it is used in multiple occasions within WIVERN. The Thorlabs achromatic lenses are ACT508-300-B and ACT508-250-B. After the pupil these two lenses are found again, representing the symmetric nature of the design. The custom lenses are identical—only one design is ever used, at present, in WIVERN. The radii of curvature of this lens is 40.238 mm (R1) and 36.765 mm (R2) and it is made of BK7 with a MgF_2 AR coating.

2.2 Deformable Mirror and Camera sub-systems

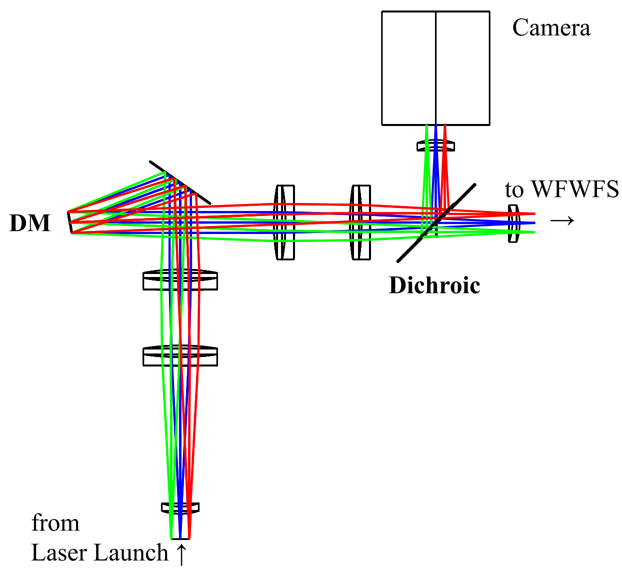

Figure 8. The DM sub-system is essentially two back-to-back F2P relays with the DM at the intermediate pupil conjugate. In addition, a shortpass dichroic allows, together with an additional F2P singlet, for the field to be imaged onto a wide-field camera. It is intended only diffraction-limited sources are viewed on this detector. The shorter wavelengths are interfaced to the next sub-system, the WFWFS.

The output of the laser launch is interfaced with the input of the Deformable Mirror sub-system, Figure 8, which also effectively contains the Camera sub-system optics hence we discuss them together. This optical design consists of two more copies of the F2P relay, with the DM placed at the intermediate pupil, via a fold mirror, and with the output of the second relay split: longer wavelengths than 745 nm go to the Camera and the remainder to the WFS. The Camera optics very simply consists of the final F2P lens, since the dichroic is placed within the final F2P relay and so the default optical interface of a f/10.84 flat output is imaged onto the detector chip. This is possible because the detector, a ZWO ASI 183MM Pro, has a large 13.2 by 8.8mm chip with 2.4 micron pixels i.e. over-sampling the PSF (10×) over a 1.04' by 0.70' field. Returning briefly to the deformable mirror itself, the model is an ALPAO DM241 which has a clear aperture (38.5 mm diameter) controlled by a 16×16 actuator array, but for cost reasons we only illuminate a 7×7 region (14.5 by 14.8 mm elliptical diameters) since this will correct for the aberrations of concern in our initial experiments. (This is a consequence of using the same F2P relay throughout WIVERN, a different relay with longer focal length lenses would enlarge the re-imaged pupil and so offer higher resolution control of the wavefront at the cost of a new optical design and requiring more physical space.)

2.3 Wide-Field Wavefront Sensor sub-system

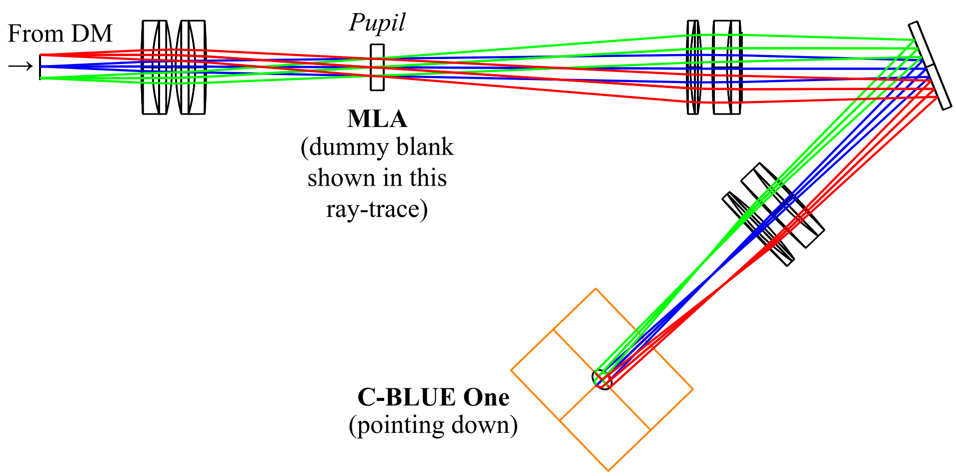

Figure 9. The WFWFS sub-system has the same optical interface as other sub-systems in WIVERN, and is essentially a pupil imager, onto a MLA, and then a relay to image the individual sub-aperture images onto the detector, a C-BLUE One, which points down and is illuminated via a fold mirror. Notably no field stop is required although one could be inserted at the interface.

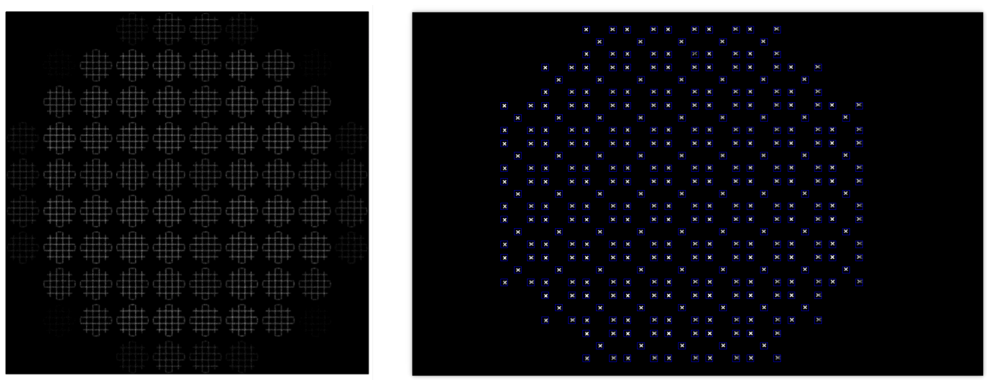

Figure 10. (Left) The expected images from the WFWFS design, based on a ray-trace simulation. (Right) From a very similar design (the same MLA and the same detector chip), a quincunx pattern over a 1 arcminute field-of-view.

The final sub-system's optical design to discuss is the Wide-Field Wavefront Sensor (WFWFS). Shown in Figure 9, the WFWFS accepts the telecentric output of a F2P relay and reimages the pupil onto a 10×10 region of a MLA to produce a wide-field Shack Hartmann WFS. The sub-aperture images are subsequently re-imaged onto a First Light C-BLUE One camera[†]. Each sub-aperture can resolve a region of 1 arcminute (square) for a 4 m pupil, with a simulation of the expected output on our detector shown in Figure 10. Using the WFS targets in the Exterior sub-system, all can be imaged by every sub-aperture and so if they are illuminated, the centroid

[†]https://www.first-light-imaging.com/product/c-blue-one/

in any sub-aperture can be computed from one, or more, guide stars either collectively (cross-correlation) or individually (point-source centre-of-gravity). The former is equivalent to SCAO for Solar telescopes while the latter is equivalent to several star-oriented NGS WFSs. Therefore, we have the flexibility in this one sub-system to emulate many AO WFS variants. It is the combination of this sub-system's detector and the ALPAO DM that places a practical limit on bench loop rate of 500 Hz, allowing realistic real-time computation experiments to be enabled.

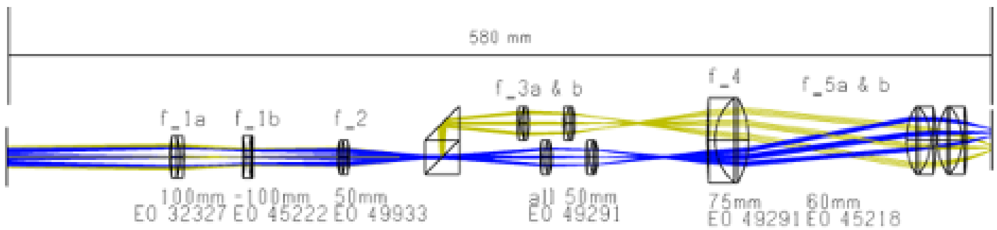

Figure 11. A prototype design for an alternative WFS, the POSSUM (Polarised Objects Side-by-Side retUrn iMager) optical design which is used to re-image two planes at different conjugates alongside each other where the planes can be distinguished using linear polarization. This WFS is for PPPP experiments.

A brief mention is now made of the alternate WFS design which is in an early stage of completion. This is the PPPP WFS and develops the idea from Yang ‡ of using polarization to split a beam into two components and from each to re-image a plane with a different conjugate distance from the pupil. This re-imaged, defocused pupil concept is the fundamental measurement in PPPP. The key difference here is to use one detector with the concept of a linear design, instead of Yang's separated detectors. A conceptual model is shown in Figure 11 and by altering the offset distance of the prism from the beam-splitter, some flexibility in the difference in the conjugate plane distances imaged is achievable. This would require abandoning the integrated optic that is currently shown (Edmund Optics 47-191) and developing a bulk-optics alternative. Because the polarisation is not controlled in WIVERN, the orientation of the p and s components is unknown until AIT and this implies this entire arm may be required to be rotated about the input optical axis to align beam-splitter axes with the input axes: therefore the mounting of the PPPP WFS and detector is required to be compatible with rotation of, at least, the optics from, and including, the beam-splitter to the final plane imaged on the detector. The counterparts for PPPP experiments are in the Laser Launch and Exterior. In the LL, a 633 nm laser is used and the the dichroic is replaced with a 50:50 intensity beam-splitter. In the Exterior, the free-space scattering region requires polarisation control via rotation aligned to the input laser's linear polarisation and then a beam-splitter to allows different conjugate planes to back-scatter with orthogonal polarisations, emulating two differently defocused pupils. This conceptual model is designed to enable easy AIT and a low-cost, efficient design solution.

3. MECHANICAL DESIGN

The realisation of the WIVERN experiment on the bench is deliberately planned to make maximum use of commercial off-the-shelf mechanics and employs simple, easily re-configurable design elements to support its usage as a modular experimental testbed. A CAD visualization is shown in Figure 12, demonstrating extensive use of parts from Thorlabs, Newport, and Edmund Optics.

The notable exception to this is the turbulence simulator module, in Figure 13. This is an electro-mechanical system that permits the insertion of up to two phase screens into the optical path to simulate variable wavefront aberrations akin to turbulence. The screens, referred to above in the optical design, are purchased ready mounted in motorized rotation stages (Lexitek LS-100§) which have been assembled into self-contained hardware modules with ergonomic handles, covers and, crucially, a dissociable electrical interface on their underside. This interface makes use of cost-effective D-sub connectors for both motor power and datum signal lines which enable the modules to be easily reconfigured. A module can be inserted at either a fixed location, representing the ground

‡http://etheses.dur.ac.uk/13260/

§http://lexitek.com/ls100.html

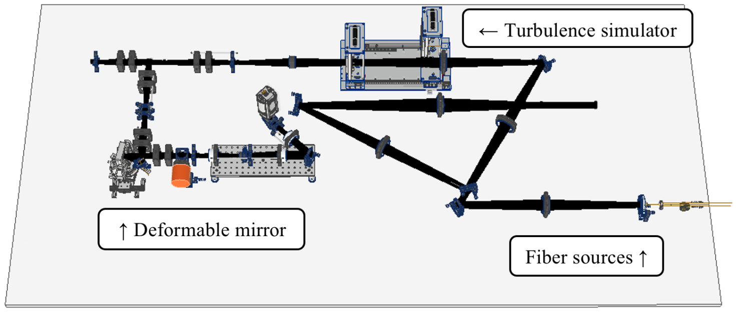

Figure 12. A CAD rendering of the implementation of WIVERN. To note is the use of standard opto-mechanics with exceptions being the mounting of the phase screens in the Turbulence Simulator, the Deformable Mirror and the Fiber Sources. The WFWFS is placed on a platform so it can be easily removed, with kinematic stops, and replaced with another WFS design, with the C-BLUE One camera installed on its own independent mount (not shown) so that this detector can also be reused in other projects more easily. The observant reader will note the design is reflected from the ray-tracing previously shown: this change was made to better route cables given our laboratory's layout and does not affect the design since all reflections are from flat surfaces.

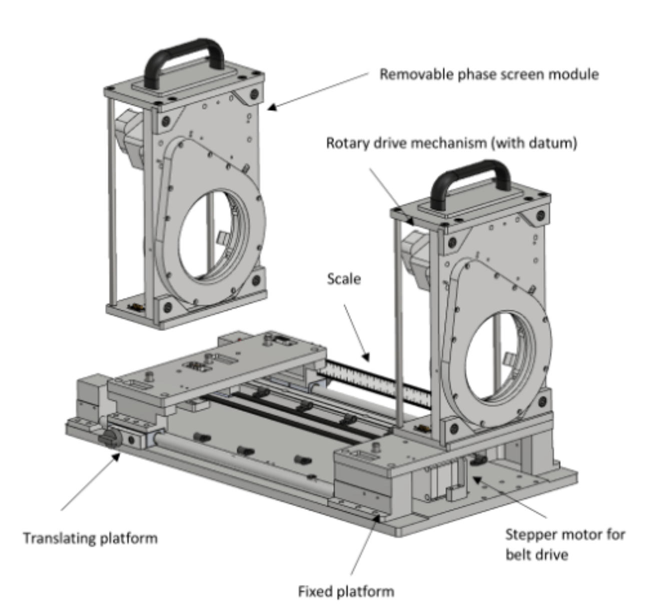

Figure 13. A CAD visualization of the turbulence simulator showing the fixed screen in place and the translating module being swapped out of the optical path.

layer, or on a translation stage which can be displaced a known (scaled) distance along the optical axis from the ground layer screen by means of a belt driven mechanism. When not in use the modules can be stowed adjacent to the optical path, as shown in Figure 12. Once the desired configuration has been setup, the screens can be rotated independently of each other. This design both helps preserves the phase screens, which have integrated covers, and permits their easy reuse in other experiments.

Another customized component is the manually adjustable mount for the ALPAO DM-241, in Figure 14. This was based on an existing in-house ALPAO DM housing mount[6] for other ALPAO deformable mirror housings and permits the following key motions: rotation about the centre of the mirror surface in both horizontal and vertical axes; translation parallel to the mirror surface vertically (via a worm drive) and horizontally (via a

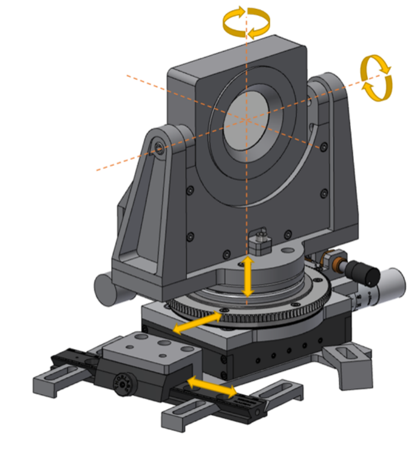

Figure 14. The ALPAO DM241 installed in our custom package. See the text for details on the alignment motions available.

Thorlabs PT1/M stage) ; coarse translation at a 10° angle using a guide.

4. ELECTRONIC DESIGN

The components which are under computer control in WIVERN consist of the turbulence simulator, the fiber point-sources (although not currently the laser launch's light sources), the deformable mirror, and finally the two detector cameras in the Camera & WFWFS sub-system. It is worth recalling that our aim is to produce an experimental test-bed and so we wish to have maximum flexibility in overall control so new algorithms can be rapidly deployed in any programming language and without computational restrictions. The core control computer runs Linux but users can interact via any OS, via an optional Jupyter[7] interface.

The turbulence simulator has three motors, all driven by a single commercially available drive controller manufactured by M5Stack [¶]. This is an integrated solution comprising an Arduino based step generation sub-system and stepper drive circuits. The motors are commanded by sending simple text instructions over an i2c bus. Two NEMA17 size stepper motors in the Lexitek stages provide the rotary motion of the phase screens. These can rotate continuously in either direction and have an optical sensor which allows the phase plates to be re-positioned to a known starting position. As recommended by the manufacturer, the motors are software limited to a maximum of up to 10 rpm equivalent to 60º/s. The translation stage for the second phase screen is also driven by a NEMA17 motor via a belt drive which is capable of positioning the screen to approximately +/-0.5mm. At each end of the linear travel a small microswitch acts as an end-stop. The fiber target LED's are directly driven, and therefore controlled, using uPython on a Raspberry Pi Pico[‖] that is connected to the main computer.

The deformable mirror is a model (ALPAO DM-241) with which the Durham group has experience[8,9] and has a straightforward one-way Ethernet interface i.e. UDP packets are sent directly from the control computer and there is no useful feedback to use for wavefront control.

The two cameras are rather different. The ZWO ASI183MM Pro has a USB3.0 interface which requires a powered hub for reliable operation over distances exceeding the assumed 3m limit which was a useful guide for our purposes (noting that the USB reference[10] suggests that quality of cable is actually our limiting factor). The software interface for ZWO cameras is based on the manufacturer API and an open source Python wrapper[**] and with triggered readout into shared memory.[11] This permits any process to acquire the last image asynchronously from the actual image acquisition procedure.

[¶]https://shop.m5stack.com/

[‖]https://www.raspberrypi.com/documentation/microcontrollers/raspberry-pi-pico.html

[**]https://github.com/stevemarple/python-zwoasi

The First Light C-BLUE One was chosen for its large size pixels (9 microns) and high frame-rate, approximately the same for full-frame readout as the DM-241 (we intend to limit WIVERN operation to a loop rate of 500 Hz). We plan to use the optional Gigabit Ethernet fiber output when it becomes available because it permits easier cable runs to our control computer, in a separate room, and the Genicam interface over GigEVision is a well-understood API which is control computer agnostic.

5. STATUS

As of the date of writing, the AIT is in an advanced stage with all powered optics purchased, almost all flat optics received, and similarly almost all mechanical components–custom and CotS–in-hand. Figure 15 shows that our design has excellent on-axis optical quality. We expect to complete all alignment by Q4 2022 and intend to present results at forthcoming meetings, including SPIE Astronomical Telescopes & Instrumentation 2024 in Copenhagen.

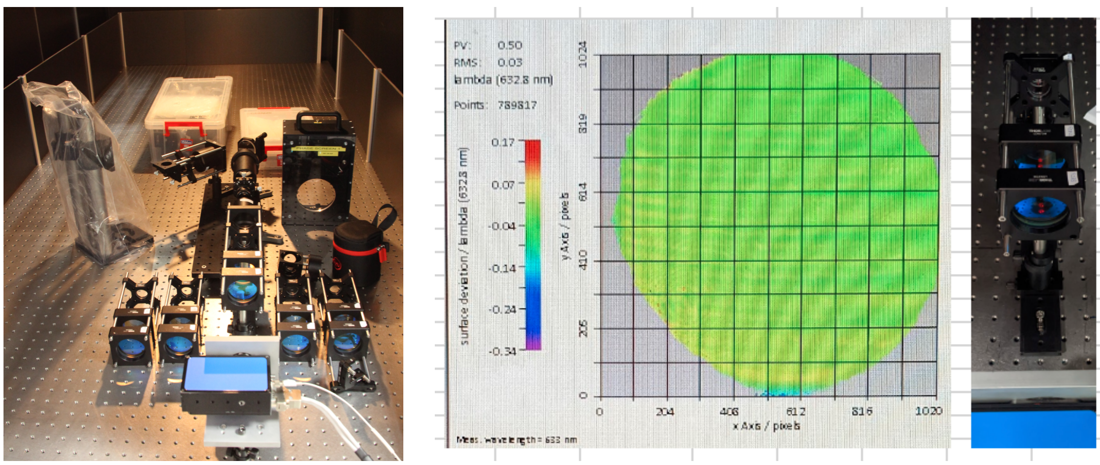

Figure 15. Our AIT efforts to date: using the modular nature of the optical design, all the F2P relays have been built rapidly and can be optically calibrated *ex situ*. One customised phase screen mount is shown ex base (under manufacture). Missing but present are the C-BLUE One WFS camera (awaiting firmware upgrade) and the ALPAO DM-241 (awaiting the custom mount). The ZWO ASI 183MM Pro camera for the Camera sub-system is shown but awaiting a commercial mechanical adapter. Our control computer is installed in a separate room (Dell PowerEdge R740 running Rocky Linux 8.3). The interferometer image shows the double-pass optical quality is excellent for one example. (The PTV value is biased by a small error at the lower edge which is the shortcoming in alignment of our interferometer mount.)

6. CONCLUSIONS

WIVERN is a designed, and under-construction, astronomical adaptive optics experimental laboratory testbed for investigating non-LGS GSL techniques such as the PPPP concept and random speckle back-scattering. It inherits from our mature design heritage and exploits modern technologies to both enable fast AIT, a flexible design with common optical interfaces allowing easy reconfiguration, and novel solutions to replicating the atmospheric environment in the laboratory. Due to supplier issues, the bench is delayed but we expect initial AIT to be complete by Q4 this year and initial results following shortly after this date.

We demonstrate a design which separates the GSL uplink beam from the NGS-equivalent emulation, using fiber optic sources, and permits at least two forms of back-scatter emulation: using fluorescence or polarisation conservation. The latter is the key technique to emulate two different conjugate planes back-scattered from the atmosphere that could be, for example, achieved in realisty with a pulsed GSL and a time-gated detector. Instead here we use the p and s planes together with an entirely novel WFS design, POSSUM.

Leveraging commercial components, specifically custom inscribed phase screens, has allowed for cost to be relatively low. In passing we note that the optical interfaces are identical to those of the CANARY on-sky experiment which could permit in-lab verification in the future if deemed useful, before deployment inside of CANARY.

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