High-order AO in the visible, The Durham High-Order demonstrator

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1. Introduction and aim

The Durham High-order Demonstrator (DHD) is a proposed XAO instrument design for the 4.2m-class William Herschel Telescope on La Palma, Canary Islands. Our principal interest in this instrument is designing a flexible-testbed into which we can use our expertise in AO to develop high-order AO which is suitable for visible observations. Addtionally, it then becomes a facility which provides a high-order AO corrected beam for further instrument development such as coronography.

This poster shows our design and limiting performance estimates. Included is a novel wavefront sensor designed to characterise the corrected beam PSF and resolve quasi-static aberrations that lead to long-term speckle. Finally we note the scientific targets of opportunity of XAO on 4m-class telescopes.

2. Overall design

Fig 1 (right) shows the basic design of the DHD, consisting of a NGS high-order WFS, a split 'woofer-tweeter' DM design and a low-bandwidth characterisation WFS. Assuming a median Fried coherence length of r_0=12 cm, the natural choice for the WFS will be a 30x30 Shack-Hartmann design with optional spatial filter to reduce effects of spatial aliasing. The corresponding high-order DM is a 1k Boston MEM mirror, while the choice of low-order DM is currently a higher-stroke 144-actuator Boston MEM mirror. The RTC will consist of the in-house DARC system which has flexible CPU, GPU, or FPGA capabilities and this will permit easy characterisation of various control algorithms to be implemented on-sky.

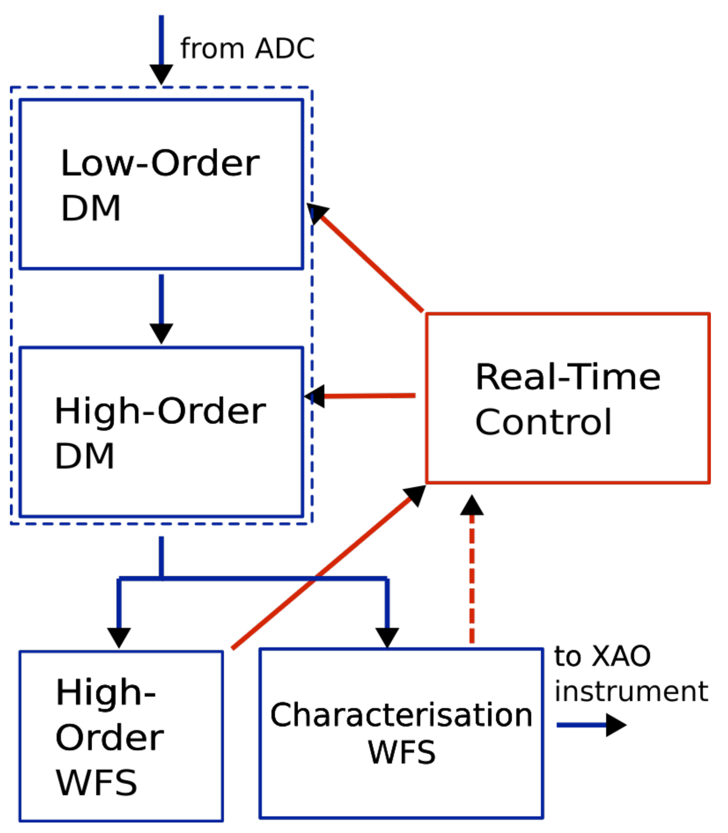

Fig 1. Overview of the DHD system architecture. Blue represents the path the light takes, red represents control signals.

These aspects will be controlled at 1kHz. The characterisation WFS is of a new design (see following panel) and is intended for two purposes: first, to act as a characterisation instrument for the PSF, and, second, integrated into the RTC for XAO imaging where high-contrast imaging is required. In this second case, the characterisation WFS is required to measure any quasi-persistent but changing phase errors. It can achieve the first task by use of its spatial filter which permits the intensity of the PSF core to measured relative to the overall throughput.

3. Performance simulations, XAO component

Using the parameters in panel 2, a Monte Carlo simulation of the SCAO system was carried out assuming additionally a camera with readout noise of 5e$^-$ at high-light levels (m_V=0). The resulting Strehl ratios are shown in fig 2.

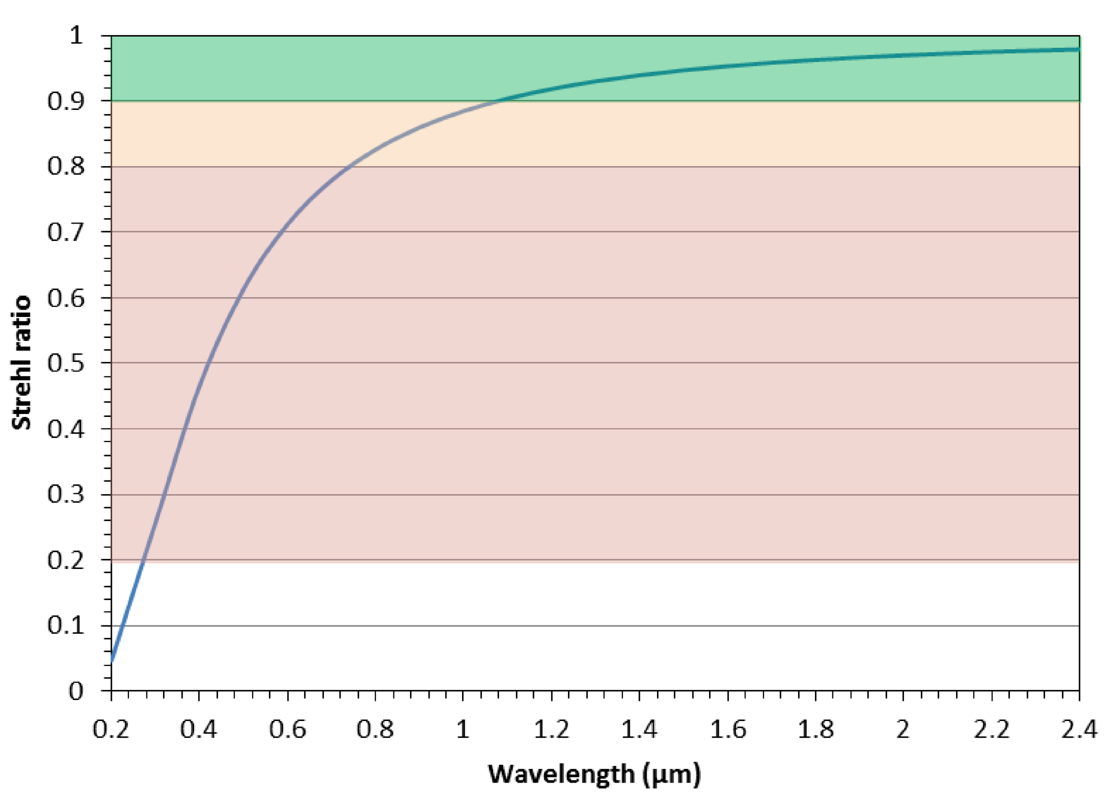

Fig 2. Expected Strehl ratios from the XAO component assuming realistic CCD parameters. The green region represents XAO-quality correction. No variability in throughput was explicitly considered.

In this idealised case (aligned optics, high-light level, no telescope vibrations) it is clear that suitable performance can be achieved in the near-IR for XAO capabilities but good correction is available into the visible.

(continued)

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(continued) 3. Performance of XAO

Further simulations were carried out to assess the effects of varying guide-star flux. Fig 3 demonstrates that for currently available CCD or CMOS technology, the limiting magnitude is m_V=4 to retain XAO performance, but good correction is retained to m_V=7.

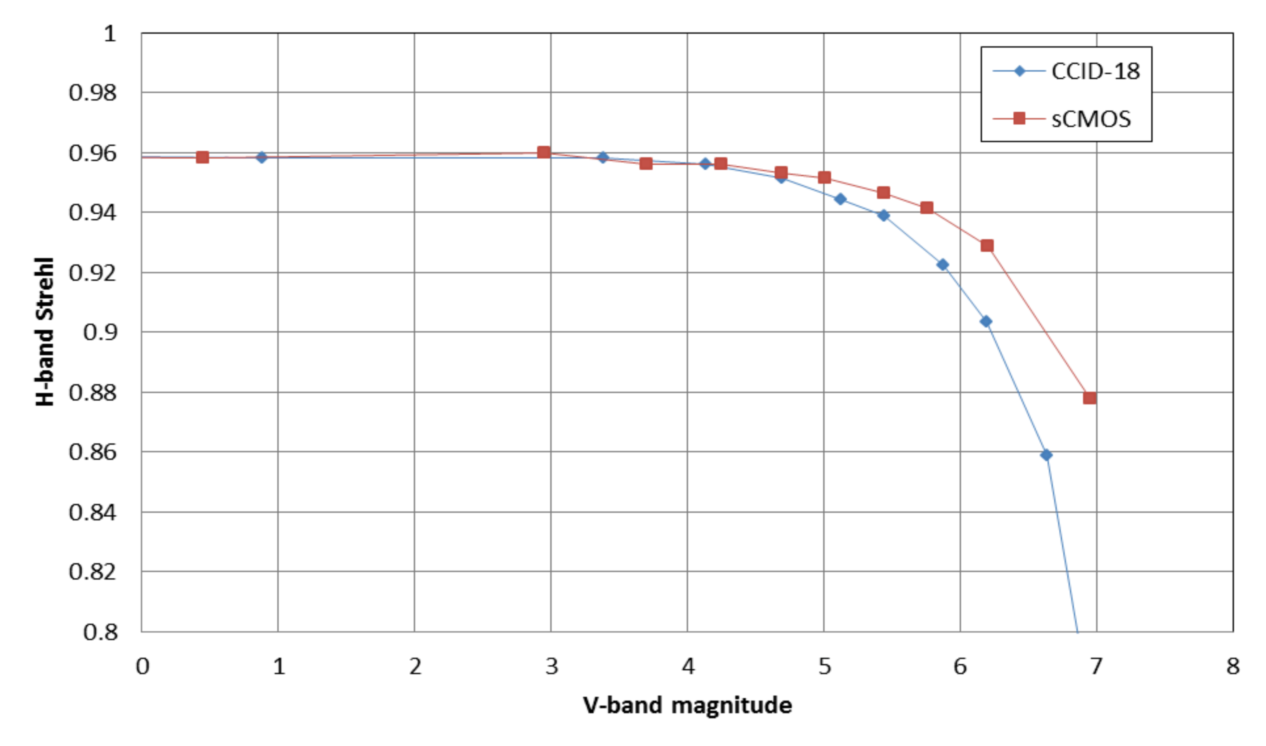

Fig 3. Effects of varying NGS guide-star brightness, using a model for a CCD camera (7e- read-noise, 85% QE) and a CMOS camera (5e- read-noisy, 57% QE).

3. Characterisation WFS

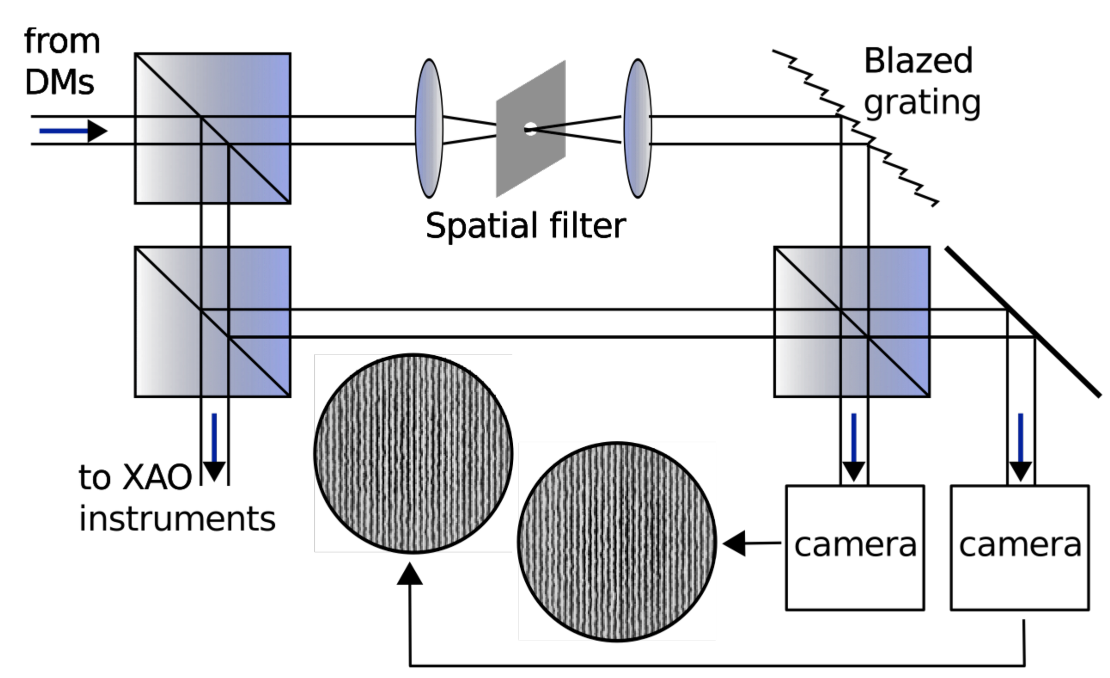

Fig 4. The characterisation WFS. The design is a combination of a Mach-Zhender interferometer with A point-diffraction interferometer. In comparison with a SH WFS, this design is ~100 times more sensitive.

The characterisation WFS concept is shown in fig 4. It is an approximately achromatic interferometer, made possible by use of the blazed optic to introduce achromatic tilt into a spatially filtered beam in one arm of what is otherwise a Mach-Zhender design. When interfered with the unfiltered beam, this results in pairs of fringe patterns at the outputs which are π out of phase. If these images are subtracted, then the Fourier transform results two side-bands that are from the fringe term. Filtering out one side-band and applying an inverse transform leaves a complex term whose phase *directly* estimates the input phase. Per sub-aperture, at a minimum 4 pixels are required.

Several issues are important to estimate performance. To retain a fringe visibility of at least 0.25 over R-band, assuming a flat-spectrum, requires aberrations be limited to λ/2. Naturally, using a narrower filter results in a larger range. However, expected XAO performance in R is ~λ/10. This implies the spatially filtered beam will retain consistently high-throughput. For 1 second integration times, the atmospheric aberrations will be removed. Finally, working in the visible, only issues of photon noise need be considered with a EMCCD. If 1% of the incoming beam is diverted to the characterisation WFS, 10% throughput overall, using a 1s integration time, and a requirement for errors of λ/100 (Strehl~=0.995) then the limiting magnitude is m_R=10.

4. XAO science & opportunities

The DHD is intended to be an open design upon which XAO technologies such as coronographs, DM control, and issues of persistent speckle can be studied and implementations attempted. As such its target location is the gravity-stable Nasmyth platform of the WHT telescope.

As regards science opportunities, the clearest are those which benefit from the high-constrast ratios with XAO: circumstellar debris discs, including the internal structure especially where exoplanet locations are involved (e.g. Formalhaut or β Pictoris); the imaging and astrometry of close binaries although interacting pairs are unlikey to be resolvable; follow up studies of evolved super-giant stars such as Betelgeuse or Mira variables.

The use of one sodium LGS for XAO is not possible for a 4m pupil if high-constrast ratios are required, but we can estimate from our results that for a LGS brightness of m=10, that a Strehl ratio of ~0.7 can be achieved using the same geometry and accounting for focal anisoplanatism. This offers, for example an opportunity for integrations on faint stars for companion searches, such as brown dwarfs or even directly brown dwarf binaries.