This is the published version of:

Michael Goodwin; Jessica Zheng; Jon Lawrence; Samuel Richards; Alexander Arriola; Nick Cvetojevic; Simon Gross and Barnaby Norris

Access to the published version:

http://dx.doi.org/10.1117/12.2232241

Copyright:

Copyright 2016 Society of Photo-Optical Instrumentation Engineers (SPIE). One print or electronic copy may be made for personal use only. Systematic reproduction and distribution, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper are prohibited.
Adaptive optics on-sky demonstrator for the Anglo-Australian Telescope

Michael Goodwin*a, Jessica Zhenga, Jon Lawrencea, Samuel Richardsa, b, c, Alexander Arriolac, d, Nick Cvetojivic, b, c, Simon Grossc, d and Barnaby Norrisb

aAustralian Astronomical Observatory, PO Box 915, North Ryde, NSW 1670, Australia; bSydney Institute for Astronomy, University of Sydney NSW 2006, Australia cCentre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS), Australia dMQ Photonics Research Centre, Department of Physics and Astronomy, Macquarie University, Sydney Australia eARC Centre of Excellence for All-sky Astrophysics (CAASTRO)

ABSTRACT

The Australian Astronomical Observatory is currently investigating the use of adaptive optics technologies for the 3.9m Anglo-Australian Telescope at Siding Spring Observatory. It might be that ground-layer or multi-object adaptive optics is beneficial for the Anglo-Australian Telescope (seeing ~1.5”). Key to achieving this goal is an adaptive optics test-bench developed for laboratory experiments and on-sky demonstration. The test-bench provides a facility to demonstrate on-sky natural guide star adaptive optics as well as second stage correction with active injection into single mode waveguides. The test-bench provides wide field access of up to 20 arcminutes for testing our plug-plate distributed wavefront sensors. Data has been collected in a range of seeing conditions where closed-loop corrections were performed. We present the design, results and plans for the adaptive optics on-sky demonstrator.

Keywords: Adaptive Optics, Test-bench, Anglo-Australian Telescope, Shack-Hartmann, Wavefront-Sensors

1. INTRODUCTION

The Anglo-Australian Telescope (AAT) is a 3.9 m diameter optical/infrared telescope commissioned in 1974. The telescope is located in the beautiful surrounds of Siding Spring Observatory, Australia. The telescope is operated and maintained by the Australian Astronomical Observatory (AAO). The telescope provides astronomers with vital access to exciting regions of the southern hemisphere skies, such as the central regions of our Milky Way Galaxy and the Magellanic Clouds. The AAT is considered one of the finest telescopes in the world, particularly during its earlier years, for its high quality optics, excellent mechanical stability and precision computer controls. A key success factor of the AAT is its state-of-the-art instrumentation that is continually being upgraded and improved.

The purpose of adaptive optics on the AAT is to improve the image quality in terms of resolution and detection of faint sources. A good overview of adaptive optics can be found in the book by Hardy [1] titled Adaptive Optics for Astronomical Telescopes. The lights from astronomical sources are distorted when passing through the atmosphere because the tiny pockets of hot and cold air act like many lenses and prisms. The telescope is unable to focus the light to its diffraction limit. The use of adaptive optics requires the measurement of the incoming optical wavefront and applying the correction on a deformable mirror in order to flatten the wavefront. This is done in real-time at high sampling rates (100’s Hz) in order to keep up with the turbulent layers moving across the telescope aperture. When successful, the improved image quality can significantly enhance the science output and increase telescope productivity.
The concept of adaptive optics on the AAT has been explored in a paper accepted back in 1995 [2]. The project involved a consortium of Australian universities (including University of Sydney) and the AAO to implement an adaptive optical system at the AAT. The first stage being a fast tip-tilt system (APD quad-cell) installed in the west coude room following a second stage low-order deformable mirror (13 electrode bimorph). Both project stages to make use of the IRIS infrared camera/spectrograph [2]. The paper concluded that ‘the science objectives are likely better served with an adaptive optics system at the Cassegrain focus’. It also stated that low-order correction to ‘dramatically enhance infrared performance, especially at K-band in good seeing’. The project did yield experimental on-sky AAT results during 24-26 March 1997 for fast tip-tilt correction in K-band with varying amounts of improvements in the FWHM (up to 1.5x) [3]. The bimorph mirror for high-order correction was not tested on the AAT [Bryant J.J, personal communication, May 26, 2016].

A few years later, interest was again renewed in adaptive optics with a subsequent grant in 2003 titled ‘Adaptive Optics for Australian Astronomy, Medicine, Industry, and Defence’, funded by the Australian Research Council and managed by the Australian National University (late Prof P. McGregor as PI) [4]. Under the funding scheme Special Research Initiative the grant awarded $20K to establish a Research Network for Adaptive Optics that ‘aims to draw together isolated Australian and New Zealand research groups working on adaptive optics applications in disparate areas to achieve a critical mass of researchers’ [4]. In the following years 2005/2006 the Australian National University had continued interest in adaptive optics with the measurements of the optical turbulence profile above Siding Spring Observatory [5]. This effort was largely motivated by the need to predict the statistical performance of adaptive optics at Siding Spring [6]. In recent times (2016), the Australian National University motivations for astronomical adaptive optics stem from their construction of ‘the Giant Magellan Telescope Integral-Field Spectrograph (GMTIFS) and developing adaptive-optics solutions for the project’ [7].

Keeping with Australia’s astronomical community’s interest in adaptive optics, the Instrument Science Group at the AAO has embarked on a research and development project to investigate the use of adaptive optic technologies for the AAT. It could be that adaptive optics is the solution that enhances the AAT productivity for the years ahead. The technology and cost are now significantly more feasible since the early AAT tip-tilt experiments in 1994. The Instrument Science Group at the AAO is also dedicated in exploring new instrument technologies for the AAT. Since 2013, the project has been working towards an adaptive optics technologies for the AAT. A project milestone is the first result of stable closed-loop high-order wavefront correction on the AAT in mid-2015. The project aims to explore adaptive optics over wide fields such as ground-layer and multi-object adaptive optics (MOAO) [18]. The project also aims to explore novel technologies such as distributed wavefront sensors (miniature Shack-Hartmann [8] and curvature sensors [9]) positioned by Starbugs [10]. Therefore, the project is aligned with the AAO’s goal of providing the AAT with state-of-the-art instrumentation and technology to deliver the best scientific outcomes.

This paper describes the AAO’s adaptive optics test-bench which has been successfully demonstrated on-sky using the 3.9 m AAT. The Section 2 discusses briefly the simulation results of the test-bench to put in perspective the expected performances to be achieved on-sky with the AAT. Following this is Section 3, an overview of the lab test-bench describing the key components of the system. We then document the test-bench for the actual on-sky adaptive optics demonstrator in Section 4, detailing its optical schematic and interfaces with the AAT. Following this is Section 5 that documents the data and on-sky results. Lastly, concluding remarks in Section 6.

2. SIMULATIONS

The predicted performances of several types of adaptive optic systems on the 3.9 m AAT have been simulated using a site-based model of the optical turbulence profile (or model-OTP) by Goodwin et. al [6]. The model-OTP being derived statistically from turbulence profiles measured 2005/2006 at Siding Spring Observatory [5]. The simulations cover the performances for single conjugate adaptive optics (SCAO), multi-conjugate adaptive optics (MCAO) [11] and ground-layer adaptive optics (GLAO) [12] for astronomical wavelength bands J, H and K. The most promising results found by Goodwin et. al [6] are for GLAO simulations (field of view of 180 arcsecs), where the encircled energy 50% diameter (EE50d) was uniform and minimally affected by the free-atmosphere turbulence. The GLAO field mean of EE50d is between 200 mas to 800 mas, which is a noticeable improvement compared to the nominal astronomical seeing (870 to 1700 mas). The MCAO simulations show sensitivity to the ground layer with ‘bad’ conditions providing the poorest EE50d. The SCAO being sensitive to the turbulence strength in the free-atmosphere, requiring ‘good’ conditions in K-
band for the best Strehl. The parameters for SCAO simulations for the 3.9 m AAT being a 10W laser guide star (LGS), 14x14 Shack wavefront sensor (WFS) at 500 fps, 171 actuator deformable mirror (DM). The H-band Strehl ranging between 0.1 to 0.6 depending on the conditions (model-OTP).

The analytical simulations using parameters specific to the test-bench (see Table 2) with the site model-OTP (see Table 1) are listed in Table 3. These simulated values in Table 3 are provided by Puttiwat Kongkaew as part of his student fellowship project at the AAO [13]. The simulation reports the variance error (radians of phase squared) for key model components. This is useful to determine which component is under-performing. Note that the model-OTP represents nine conditions for the ground-layer and free-atmosphere that statistically represent 50% of cases around the median seeing. From the simulated results listed in Table 3, the Strehl H-band ranges from 0.23 to 0.76 or RMS wavefront error of 0.3 to 0.1 microns.

From Table 3, the DM is currently the limiting component due insufficient actuators (97 actuators), as the phase variance error \( \text{Var}_{\text{DM}} \) is a significant fraction of the total variance. The temporal sampling (200 Hz) variance \( \text{Var}_{\text{TIME}} \) is significant for bad seeing conditions (poor than 1.3”, model-OTP #6 to #9) and significant for poor free-atmosphere turbulence where \( \text{Tau}_0 \) and \( \Theta_0 \) are small. For typical seeing conditions 1.3 to 1.7” the simulations show that the test-bench predicted performance on the AAT can achieve H-Band Strehls 0.2 to 0.4. Simulations indicate that to improve the Strehl requires upgrading the DM having more actuators as well as increasing the temporal sampling.

<table>
<thead>
<tr>
<th>Model-OTP</th>
<th>Seeing V (&quot;)</th>
<th>Tau_0 (ms)</th>
<th>Theta_0 (&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8659</td>
<td>11.7922</td>
<td>6.4233</td>
</tr>
<tr>
<td>2</td>
<td>0.9436</td>
<td>5.3516</td>
<td>3.7172</td>
</tr>
<tr>
<td>3</td>
<td>1.0755</td>
<td>2.3291</td>
<td>2.0123</td>
</tr>
<tr>
<td>4</td>
<td>1.1787</td>
<td>4.5855</td>
<td>6.3684</td>
</tr>
<tr>
<td>5</td>
<td>1.2427</td>
<td>3.5038</td>
<td>3.7043</td>
</tr>
<tr>
<td>6</td>
<td>1.3542</td>
<td>2.0310</td>
<td>2.0098</td>
</tr>
<tr>
<td>7</td>
<td>1.5206</td>
<td>2.2067</td>
<td>6.2255</td>
</tr>
<tr>
<td>8</td>
<td>1.5749</td>
<td>2.0112</td>
<td>3.6700</td>
</tr>
<tr>
<td>9</td>
<td>1.6710</td>
<td>1.5242</td>
<td>2.0030</td>
</tr>
</tbody>
</table>

Table 1: Summary of Model-OTP for Siding Spring Observatory.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope (m)</td>
<td>3.9</td>
</tr>
<tr>
<td>WFS Wav (microns)</td>
<td>0.7</td>
</tr>
<tr>
<td>SCI Wav (microns)</td>
<td>1.6</td>
</tr>
<tr>
<td>WFS Sub (m)</td>
<td>0.1696</td>
</tr>
<tr>
<td>DM (act)</td>
<td>97</td>
</tr>
<tr>
<td>Loop (Hz)</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 2: Parameters for the adaptive optics test-bench simulations.

<table>
<thead>
<tr>
<th>Model-OTP</th>
<th>( \text{Var}_{\text{WFS}} )</th>
<th>( \text{Var}_{\text{DM}} )</th>
<th>( \text{Var}_{\text{TIME}} )</th>
<th>Strehl H</th>
<th>RMS (micron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0040</td>
<td>0.2397</td>
<td>0.0234</td>
<td>0.7656</td>
<td>0.1316</td>
</tr>
<tr>
<td>2</td>
<td>0.0048</td>
<td>0.2767</td>
<td>0.0872</td>
<td>0.6917</td>
<td>0.1546</td>
</tr>
<tr>
<td>3</td>
<td>0.0062</td>
<td>0.3441</td>
<td>0.3489</td>
<td>0.4970</td>
<td>0.2129</td>
</tr>
<tr>
<td>4</td>
<td>0.0075</td>
<td>0.4008</td>
<td>0.1128</td>
<td>0.5939</td>
<td>0.1838</td>
</tr>
<tr>
<td>5</td>
<td>0.0083</td>
<td>0.4378</td>
<td>0.1766</td>
<td>0.5365</td>
<td>0.2009</td>
</tr>
<tr>
<td>6</td>
<td>0.0098</td>
<td>0.5052</td>
<td>0.4383</td>
<td>0.3855</td>
<td>0.2486</td>
</tr>
<tr>
<td>7</td>
<td>0.0124</td>
<td>0.6128</td>
<td>0.3817</td>
<td>0.3653</td>
<td>0.2555</td>
</tr>
<tr>
<td>8</td>
<td>0.0133</td>
<td>0.6497</td>
<td>0.4455</td>
<td>0.3300</td>
<td>0.2681</td>
</tr>
<tr>
<td>9</td>
<td>0.0150</td>
<td>0.7171</td>
<td>0.7073</td>
<td>0.2371</td>
<td>0.3055</td>
</tr>
</tbody>
</table>

Table 3: Results of analytical simulations for the adaptive optics test-bench.
3. TEST-BENCH OVERVIEW

The ability to evaluate and test adaptive optics technologies in the laboratory with a test-bench is a prerequisite to demonstrate adaptive optics on-sky with the AAT. A labeled photo of the AAO adaptive optics test-bench is shown in Figure 1. The test-bench in Figure 1 is currently configured for laboratory use to test our prototype 12x12 mini-WFS (wavefront sensor #2). It is configured in the basic single conjugate adaptive optics mode where the wavefront source is also the science object. The test-bench has also been used to investigate adaptive optics for the recovery of optical angular momentum [14] and for active injection into single mode wave guides [15]. The laboratory test-bench is mounted to Cassegrain focus of the AAT in an inverted position with a few modifications.

The reference source is a fiber laser collimator that combines two wavelengths, 660 nm and 1310 nm, using a fiber coupler. The power can be individually controlled to simulate different source brightness. This configuration simulates the nominal operation where the short wavelength goes the wavefront sensor and the long wavelength goes to science object where improved imaged correction is achieved. The output of the fiber laser collimator is then expanded using a beam expander to make the intensity uniform over the pupil.

The expanded collimated light then passes through a motorized phase screen to simulate a single turbulent layer atmosphere. We have two custom phase screens (100 mm diameter annular plate) manufactured by Lexitek to have Kolmogorov like phase statistics with first $r_0=0.31$ mm and the second $r_0=0.73$ mm. Both phase screens are mounted in a motorized rotary stage capable at least 100 RPM which equates to a wind speed approx. 90 m/s for a 13.5 mm pupil (DM) mapped to a physical 3.9 m AAT. The test-bench is configured for a single phase screen at the ground-layer that is placed approx. at the optical conjugate of the pupil formed on the DM and WFS. The phase screen is moved out of the optical beam in order to calibrate and build the interaction matrix of the WFS/DM.

When the test-bench installed on the AAT, the phase screens are removed and additional pick-off optics are used to collimate the telescope f/8 beam. The acquisition camera (not shown in Figure 1) provides feedback to precisely point the telescope. The tip-tilt sensor camera (not shown in Figure 1) is placed before the DM and provides tip-tilt and uncorrected seeing measurements.

The light is then directed onto the DM which forms the optical aperture stop of 13.5 mm. The DM is an ALPAO DM97-15 having 97 actuators over a circular diameter of 13.5 mm. The DM has a high stroke capable of a peak-to-valley more than 60 microns over surface and bandwidth up to 750 Hz. The DM applies both the tip-tilt and high-order wavefront corrections to achieve the best image quality. The optics between the phase screen and DM form the optical image conjugates of the pupil.

Next, the light is encounters dichroic that splits the light below 700 nm to the wavefront sensors. The light above 700 nm goes to the short-wave infrared camera (Xenics) serving the purpose as the science camera, sensitive wavelength from 0.8 to 1.8 microns. The science camera monitors the image quality of the point spread function. A bias on the DM compensates for static aberrations measured by the science camera. The beam size is de-magnified for the wavefront sensor. For the AAT a Shack Hartmann wavefront sensor is used, which consists of a 26x26 microlens array and an Andor SCMOS Zyla camera. This is capable of sampling the wavefront at least 200 Hz to keep up with the changing turbulence. For the lab setup in Figure 1 we currently have a Thorlabs WFS (wavefront sensor #1) and our prototype 12x12 mini-WFS (wavefront sensor #2).

The loop control is implement based on the stock and derived components from ALPAO software called ACE running in Matlab and Labview environment. The ACE s/w allows end-users to help prototype and build custom adaptive optics systems based on ALPAO components. The ACE s/w works well for the ALPAO hardware, such as our DM, but required additional work to implement our WFS (based on the Andor Zyla). The conjugated wavefront is reconstructed in real-time with ACE software running in Matlab and then sent to the DM. The wavefront is iteratively flattened with the appropriate loop gain for stability and performance. The front-end control GUI of the test-bench, see Figure 2, is implemented in Labview (also based on ACE components) that interfaces to Matlab. The ACE software provides the ability to implement modal or zonal reconstruction techniques.
Figure 1: AAO adaptive optics test-bench configured in laboratory to test a 12x12 mini-WFS.

Figure 2: Labview GUI that controls the AAO adaptive optics test-bench (derived from ALPAO’s ACE s/w).
4. AO DEMONSTRATOR

The AAO adaptive optics test-bench is an optical breadboard that is mounted in an inverted position on the Cassegrain focus of the AAT, as shown in Figure 3. Modifications to the lab test-bench are required such as the structural support and cabling; the removal of the phase screens; additional optics to pick-off and collimate the telescope f/8 beam; target acquisition and guiding camera and tip-tilt sensor. The optical layout of the test-bench for the AAT is shown in Figure 4. The test-bench is flexible in that it can cater for additional experiments related to adaptive optics. The test-bench has a field hole of 300 mm diameter that allows the installation of a plug-plate for distributed wavefront sensors [8, 9] experiment to access the 20 arcminute field. The test-bench has been installed on the AAT for a total of three observational runs (see Table 4) and time shared with other experiments of active injection [15] and distributed wavefront sensors [8, 9].

<table>
<thead>
<tr>
<th>Run</th>
<th>Date</th>
<th>Nights</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10 December 2014 to 11 December 2014</td>
<td>2</td>
<td>Weather issues; NIR camera not available; Evidence of tip-tilt correction in the visible with FWHM reduced by 20%. Closed-loop stable for only a few seconds.</td>
</tr>
<tr>
<td>3</td>
<td>23 Nov 2015 to 30 Nov 2015</td>
<td>8</td>
<td>Improved instrument configuration to minimize polychromatic aberrations when feeding active injection experiment. Improved procedures. Active injection observations and results. Distributed wavefront sensor plug-plate observations. Tip-tilt sensor and corrections. Improved H-band corrections on double star separation 10&quot;.</td>
</tr>
</tbody>
</table>

Table 4: Observing runs with the adaptive optics test-bench on the AAT
Figure 3: Photos showing the 3.9 m AAT and the adaptive optics Test-bench.
5. ON-SKY RESULTS

5.1 Data Description

In Section 5 we examine the results of a single observational dataset of the double star Theta Eridani (WDS 02583-4018). We use this dataset as an example of the performance of the adaptive optics test-bench that can be achieved under typical conditions. The dataset was taken during the third set of observations (run #3) at approx. 01-Dec-2015 00:52:39 (local time). Theta Eridani is a double star of separation 8.6", magnitude of primary is 3.2 and secondary is 4.12 [16]. The metrological conditions at the site reported an outside temperature of 22 degrees with an average wind speed of approx. 10 km/h and a wind direction from the north [17]. The observational data taken using a Xenics shortwave infrared (SWIR) camera with a H-band filter (1.6 microns). The camera resolution of 320 x 240 pixels provided 0.16 arcsecs per pixel sampling on-sky.

The dataset contains a total of 1000 frames taken with an approx. frame rate of 9.7 fps. To compare results, the first half of the dataset captured open-loop (approx.500 frames or 50 s) and then the remainder in closed-loop. The long exposure is achieved by averaging the frame data for the double star target for open-loop and close-loop conditions and shown in Figure 5. The wavefront source for closed-loop being the brighter primary component of the double star. For closed-loop performance we note that the double star’s secondary component is also compensated. This suggests that the isoplanatic angle of the atmospheric turbulence in the H-band during observations is larger than the double star angular separation of 8.6". In the following sub-sections we examine both the image motion and image quality in open-loop and closed-loop.
5.2 Image Motion

The image motion can be measured with the analysis of the centroid data in open-loop and closed-loop conditions. It is noted that the largest source of astronomical image degradation is from image motion (tip-tilt component of wavefront). The source of image motion is a combination of telescope guiding and the atmospheric component. For the dataset Theta Eridani we plot the mean subtracted X and Y centroid data for the primary component in Figure 6. The open-loop centroid RMS for X-direction is 0.3623" and Y-direction is 0.2585". For closed-loop the image motion is much less with a RMS for X-direction is 0.0228" and Y-direction is 0.0247". For closed-loop the reduction in image motion is more than 10x the open-loop values. For the case of open-loop, we note telescope guiding issues with asymmetry in the NE-SW directions (possibly due to our guide camera and software configuration).

In Figure 7 we use a box plot to show the centroid distribution for open-loop and close-loop. We note that the distributions in the box plot are symmetrical like about their medians. In Figure 7 we plot the power spectra to show the frequency response for open-loop and closed-loop. For open-loop we note significant power at low frequencies with two notable harmonics at 0.1 Hz and 1.9 Hz. The power value at 1.9 Hz is also evident in the power spectra for the closed-
loop X-centroid but significantly attenuated. The telescope is likely the source of the signals. The closed-loop operation successfully compensates the low frequency image motion as shown by the reduction in power of the low frequencies in the power spectra.

![Box plot](image1.png) ![Log power spectra plot](image2.png)

**Figure 7**: Plot of the X,Y centroid for open-loop (red) and closed-loop (blue) for Theta Eridani.

### 5.3 Image Quality

To measure the image quality the science camera frames in H-band are averaged from the dataset Theta Eridani. This is done for both open-loop (see Figure 8) and closed-loop (see Figure 9) operation modes for comparison.

![Open-loop long exposure image](image3.png) ![Closed-loop long exposure image](image4.png)

**Figure 8**: open-loop long exposure image (a) measurement and (b) model Moffat function.

**Figure 9**: closed-loop long exposure image (a) measurement and (b) model Moffat function.

The equivalent long exposure image (approx. 50 s) provided by averaging of approx. 500 frames. A model Moffat function fitted to data to measure the FWHM. For open-loop the model H-band FWHM is 1.44" and for closed-loop is
0.40\textquotedbl. The peak intensity of the closed-loop is nearly 5 times that of the open-loop. In Figure 10 we compare the resulting PSF of the open-loop and closed-loop with that of the reference source. The reference source serves as a calibration and therefore considered as the best image quality possible from the adaptive optics test-bench. Note that the reference source does not pass through the telescope and fore-optics which might add artefacts not corrected in the observed PSF. The peak normalized intensity of the closed-loop is approx. 16\% that of the reference. A H-band seeing of 1.44\textquotedbl is equivalent to a V-band seeing of 1.8\textquotedbl, which is worse that the seeing in model\#9 of Table 3, which predicts a H-band Strehl of approx. 24\%. Therefore, this on-sky result is in general agreement with the simulation.

Figure 10: A side-by-side comparison of the H-band normalized PSF (energy) from the left to right: open-loop (peak \sim 0.03) and closed-loop (peak \sim 0.16) compared to reference source (peak = 1.0) for dataset Theta Erinandi.

Next, we plot the 1-D profile of the intensity PSF for open-loop, closed-loop and reference source in Figure 11. From the linear plots of Figure 11, we see that the FWHM of the closed-loop PSF are similar to that of the reference source PSF. However, the closed-loop PSF has more energy in its outer ‘wings’ or halo compared to the reference source, most within seeing disk radius < 1.5\textquotedbl. We also note from the log plots the higher overall scattering in the wings of the open-loop and closed-loop PSF compared to the reference source PSF. The increased scattering may be due to the telescope mirrors and optics not in the optical path of the reference source.
Adaptive optics can deliver significant improvements to the image FWHM. However, another useful quantity is the encircled energy within a certain angular diameter. The plots for the encircled energy are shown in Figure 12. The improvement in the encircled energy with adaptive optics is less dramatic than the improvement in the FWHM. This is due to the presence of the outer-halo (size of the uncorrected seeing disk) of the partially corrected PSF. From Figure 12, the gain in encircled energy with adaptive optics for a 0.5” aperture is more than three-fold. For an aperture matched to the uncorrected seeing FWHM of ~1.5”, the gain in encircled energy with adaptive optics is only 50%. Therefore the gain in encircled energy decreases with increasing aperture size and therefore must be taken into consideration.
Encircled Energy (/1.0)

(a) Encircled energy within given diameter; open-loop (dash) and closed-loop (solid) normalized to 1.0 for 6.5\" aperture.

(b) Gain in encircled energy; closed/open within a given aperture.

Figure 12: Encircled energy plots for the H-band PSF in 1.44\" seeing.

6. CONCLUSION

This paper has documented the successful on-sky adaptive optics demonstration using the 3.9 m AAT. The AAO test-bench performed stable closed-loop correction of tip-tilt and high-order wavefront components on two separate observing runs, in July 2015 and November 2015. The result of closed-loop performance in November 2015 on the double star Theta Erinandi improved the seeing FWHM from 1.44\" (1.8\" V-band) down to 0.40\" in the H-band. The gain in encircled energy with adaptive optics closed-loop for a 0.5\" aperture is more than three-fold. The peak intensity of the measured PSF significantly improved from 3\% to 16\% relative to an ideal PSF. The historical significance of the achievement being the only adaptive optics (high-order wavefront correction) results to date on the 3.9 m AAT.

Simulations of the adaptive optics test-bench are in general agreement with observations. Simulations for typical conditions on the 3.9 m AAT indicate that performances can be improved by increasing the number of DM actuators (97) and then increasing the loop bandwidth (approx. 200 Hz). This will be given further consideration for future observations with the adaptive optics test-bench on the 3.9 m AAT.

The test-bench provides a useful mechanism to facilitate the testing of new concepts requiring adaptive optics, such as detection of orbital angular momentum; active injection in single mode waveguides and miniature wavefront sensors for Starbugs. The test-bench is a useful tool to validate these technologies in the lab and on-sky.

The next steps for the adaptive optics test-bench are to develop and validate on-sky the close-loop operation of the miniature wavefront sensors (for Starbugs); explore the operation of the GLAO and MOAO [18] modes on the 3.9 m AAT; explore science cases and instrument concepts to benefit from adaptive optics on the 3.9 m AAT. The AAO’s research activities into adaptive optics are to ensure that the AAT is equipped with state-of-the-art technology and to maintain AAO’s competitiveness for international projects with adaptive optics skills and novel technologies.
REFERENCES

Adaptive Optics Systems V

Enrico Marchetti
Laird M. Close
Jean-Pierre Véran
Editors

26 June–1 July 2016
Edinburgh, United Kingdom

Sponsored by
SPIE

Cooperating Organizations
American Astronomical Society (United States) • Australian Astronomical Observatory (Australia) • Association of Universities for Research in Astronomy (AURA) • Canadian Astronomical Society (CASCA) (Canada) • Canadian Space Agency (Canada) • European Astronomical Society (Switzerland) • European Southern Observatory (Germany) • National Radio Astronomy Observatory • Royal Astronomical Society (United Kingdom) • Science & Technology Facilities Council (United Kingdom)

Published by
SPIE

Part One of Three Parts

Volume 9909
Contents

xvii Authors
xxvii Conference Committee

Part One

SESSION 1 STATUS OF CURRENT AO PROJECTS I

9909 01 MagAO: status and science [9909-1]
9909 02 Imaka: a ground-layer adaptive optics system on Maunakea [9909-2]
9909 03 Engineering aspects of the Large Binocular Telescope Observatory adaptive optics systems [9909-3]

SESSION 2 ASTRONOMY WITH AO I

9909 05 The infrared imaging spectrograph (IRIS) for TMT: latest science cases and simulations (Invited Paper) [9909-5]
9909 06 Stellar photometry with multi conjugate adaptive optics (Invited Paper) [9909-6]
9909 07 Photometric techniques, performance and PSF characterization of GeMS [9909-7]

SESSION 3 AO FOR THE ELTS

9909 08 Adaptive optics program update at TMT [9909-8]
9909 09 The adaptive optics modes for HARMONI: from Classical to Laser Assisted Tomographic AO [9909-9]
9909 0A Joint MICADO-MAORY SCAO mode: specifications, prototyping, simulations and preliminary design [9909-10]
9909 0B Designing the METIS SCAO and LTAO systems [9909-11]

SESSION 4 PATHFINDERS, NEW PROPOSED AO SYSTEMS, AND CONCEPTS I

9909 0C Final two-stage MOAO on-sky demonstration with CANARY [9909-12]
9909 0D Keck Planet Imager and Characterizer: concept and phased implementation [9909-13]
The rapid transient surveyor [9909-15]

SESSION 5 CHARACTERIZATION, MEASUREMENT AND MODELING OF THE DISTURBANCES FACED BY AO I

FASS: the full aperture seeing sensor [9909-17]

Operational optical turbulence forecast for the service mode of top-class ground based telescopes [9909-18]

Characterizing and mitigating vibrations for SCExAO [9909-19]

SESSION 6 ADVANCES IN AO CONTROL AND CALIBRATIONS I

Review of AO calibrations, or how to best educate your AO system (Invited Paper) [9909-20]

Solving the NFIRAOS calibration puzzle [9909-21]

LQG adaptive optics control with wind-dependent turbulent models [9909-175]

SESSION 7 WAVEFRONT CORRECTORS

Deformable mirrors development program at ESO [9909-24]

A new driving method for piezo deformable mirrors: open loop control and MOAO made easy [9909-25]

SESSION 8 LASER GUIDE STAR SYSTEMS

Four generations of sodium guide star lasers for adaptive optics in astronomy and space situational awareness [9909-28]

Keck II laser guide star AO system and performance with the TOPTICA/MPBC laser [9909-29]

SESSION 9 EXTREME AO I

SAXO, the SPHERE extreme AO system: on-sky final performance and future improvements (Invited Paper) [9909-32]

Status and performance of the Gemini Planet Imager adaptive optics system (Invited Paper) [9909-33]

The SCExAO high contrast imager: transitioning from commissioning to science [9909-34]
SESSION 10  STATUS OF CURRENT AO PROJECTS II

9909 0X  A review of solar adaptive optics (Invited Paper) [9909-35]
9909 0Y  Status of the DKIST system for solar adaptive optics [9909-36]
9909 0Z  Adaptive Optics Facility: control strategy and first on-sky results of the acquisition sequence [9909-37]
9909 10  On-sky MOAO performance evaluation of RAVEN [9909-38]
9909 11  AO corrected satellite imaging from Mount Stromlo [9909-39]

SESSION 11  WAVEFRONT SENSING I

9909 12  Sub-electron read noise and millisecond full-frame readout with the near infrared eAPD array SAPHIRA (Invited Paper) [9909-40]
9909 13  C-RED one: ultra-high speed wavefront sensing in the infrared made possible [9909-41]
9909 14  AO WFS detector developments at ESO to prepare for the E-ELT [9909-42]
9909 15  Near-infrared wavefront sensing [9909-43]

SESSION 12  EXTREME AO II

9909 16  Tackling down the low wind effect on SPHERE instrument [9909-44]
9909 18  Evolutionary timescales of AO-produced speckles at NIR wavelengths [9909-46]

SESSION 13  STATUS OF CURRENT AO PROJECTS III

9909 19  Astronomical AO in Key Laboratory of Adaptive Optics, Chinese Academy of Sciences (Invited Paper) [9909-47]
9909 1A  Robo-AO Kitt Peak: status of the system and deployment of a sub-electron readnoise IR camera to detect low-mass companions [9909-48]
9909 1B  The ERIS adaptive optics system [9909-49]
9909 1C  Status of the GTC adaptive optics: integration in laboratory [9909-50]
9909 1D  First light of the deformable secondary mirror-based adaptive optics system on 1.8m telescope [9909-51]
<table>
<thead>
<tr>
<th>SESSION 14</th>
<th>ASTRONOMY WITH AO II</th>
</tr>
</thead>
<tbody>
<tr>
<td>9909 1E</td>
<td>A review of astronomical science with visible light adaptive optics (Invited Paper) [9909-52]</td>
</tr>
<tr>
<td>9909 1G</td>
<td>High-precision astrometry towards ELTs [9909-54]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SESSION 15</th>
<th>PATHFINDERS, NEW PROPOSED AO SYSTEMS, AND CONCEPTS II</th>
</tr>
</thead>
<tbody>
<tr>
<td>9909 1H</td>
<td>Solar adaptive optics: specificities, lessons learned, and open alternatives [9909-55]</td>
</tr>
<tr>
<td>9909 1I</td>
<td>Adaptive optics for MOSAIC: design and performance of the wide(st)-field AO system for the E-ELT [9909-56]</td>
</tr>
<tr>
<td>9909 1J</td>
<td>Testing the pyramid truth wavefront sensor for NFIRAOS in the lab [9909-57]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SESSION 16</th>
<th>CHARACTERIZATION, MEASUREMENT, AND MODELING OF THE DISTURBANCES FACED BY AO II</th>
</tr>
</thead>
<tbody>
<tr>
<td>9909 1K</td>
<td>Review of the outer scale of the atmospheric turbulence (Invited Paper) [9909-58]</td>
</tr>
<tr>
<td>9909 1M</td>
<td>Modelling and prediction of non-stationary optical turbulence behaviour [9909-60]</td>
</tr>
<tr>
<td>9909 1N</td>
<td>E-ELT turbulence profiling with stereo-SCIDAR at Paranal [9909-61]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SESSION 17</th>
<th>POST-PROCESSING AO DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>9909 1P</td>
<td>Point spread function determination for Keck adaptive optics [9909-63]</td>
</tr>
<tr>
<td>9909 1Q</td>
<td>PSF reconstruction validated using on-sky CANARY data in MOAO mode [9909-64]</td>
</tr>
<tr>
<td>9909 1R</td>
<td>Exploiting physical constraints for multi-spectral exo-planet detection [9909-65]</td>
</tr>
<tr>
<td>9909 1S</td>
<td>Correction of distortion for optimal image stacking in wide field adaptive optics: application to GeMS data [9909-66]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SESSION 18</th>
<th>ADVANCES IN AO CONTROL AND CALIBRATIONS II</th>
</tr>
</thead>
<tbody>
<tr>
<td>9909 1T</td>
<td>The GMT active optics control strategies [9909-67]</td>
</tr>
<tr>
<td>9909 1U</td>
<td>AOF LTAO mode: reconstruction strategy and first test results [9909-68]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SESSION 19</th>
<th>WAVEFRONT SENSING II</th>
</tr>
</thead>
<tbody>
<tr>
<td>9909 1X</td>
<td>NGS2: a focal plane array upgrade for the GeMS multiple tip-tilt wavefront sensor [9909-71]</td>
</tr>
</tbody>
</table>
### POSTER SESSION: STATUS OF CURRENT AO INSTRUMENT PROJECTS

**9909 1Z**  Anti-aliasing optical method for Shack Hartmann WFSs [9909-73]

**9909 20**  The QACITS pointing sensor: from theory to on-sky operation on Keck/NIRC2 [9909-74]

**9909 21**  Designing and testing the coronagraphic Modal Wavefront Sensor: a fast non-common path error sensor for high-contrast imaging [9909-75]

---

**POSTER SESSION: STATUS OF CURRENT AO INSTRUMENT PROJECTS (cont.)**

**9909 22**  Commissioning and first light results of an L'-band vortex coronagraph with the Keck II adaptive optics NIRC2 science instrument [9909-76]

**9909 24**  The adaptive optics system of the 1.5m GREGOR solar telescope: four years of operation [9909-78]

**9909 25**  Status and new developments with the Keck I near-infrared tip-tilt sensor [9909-79]

**9909 27**  The ZIMPOL high contrast imaging polarimeter for SPHERE: polarimetric high contrast commissioning results [9909-81]

**9909 29**  Progress in multi-conjugate adaptive optics at Big Bear Solar Observatory [9909-83]

**9909 2C**  Preliminary result of the solar multi-conjugate adaptive optics for 1m new vacuum solar telescope [9909-86]

**9909 2D**  MAORY: adaptive optics module for the E-ELT [9909-87]

### Part Two

**POSTER SESSION: STATUS OF CURRENT AO INSTRUMENT PROJECTS (cont.)**

**9909 2E**  Adaptive optics capabilities at the Large Binocular Telescope Observatory [9909-88]

**9909 2F**  Reshaping and polishing the GeMS MCAO system [9909-89]

**9909 2G**  Adaptive optics operations at the Large Binocular Telescope Observatory [9909-90]

**9909 2H**  GRAAL on the mountaintop [9909-91]

**9909 2I**  Solar adaptive optics for 1m new vacuum solar telescope [9909-92]

**9909 2K**  Performance monitoring of an AO instrument: the case of SINFONI [9909-96]

**9909 2L**  CIAO: wavefront sensors for GRAVITY [9909-97]

**9909 2M**  System tests and on-sky commissioning of the GRAVITY-CIAO wavefront sensors [9909-98]
Status of Hida solar adaptive optics system and experiment of tomographic wavefront sensing [9909-99]

Laboratory results of the AOF system testing [9909-105]

Ten years maintaining MACAO-VLTI units in operation in the Very Large Telescope at Paranal Observatory [9909-106]

On-sky AO test bench [9909-110]

Lick Observatory’s Shane telescope adaptive optics system (ShaneAO): research directions and progress [9909-111]

On-sky single-mode fiber coupling measurements at the Large Binocular Telescope [9909-112]

Rejuvenation of a ten-year old AO curvature sensor: combining obsolescence correction and performance upgrade of MACAO [9909-113]

AOF: standalone test results of GALACSI [9909-114]

CHOUGH: spatially filtered Shack-Hartmann wave-front sensor for HOAO [9909-115]

SHARK-NIR: from K-band to a key instrument: a status update [9909-116]

Adaptive system for solar telescopes operating in the strongly turbulent atmosphere [9909-117]

Adaptive optics on-sky demonstrator for the Anglo-Australian Telescope [9909-118]

NFIRAOS in 2015: engineering for future integration of complex subsystems [9909-119]

GTC adaptive optics hardware electronics [9909-120]

First on-sky results with ARGOS at LBT [9909-320]

POSTER SESSION: CHARACTERIZATION, MEASUREMENT, AND MODELING OF THE DISTURBANCES FACED BY AO

Analysis and comparison of the atmospheric parameters retrieved from a Ex-AO instrument with the astroclimatic monitoring system [9909-122]

Forecasts of the atmospheric parameters close to the ground at the LBT site in the context of the ALTA project [9909-123]

Towards an automatic system for monitoring of $C_n^2$ and wind speed profiles with GeMS [9909-129]

Online estimation of atmospheric turbulence parameters and outer-scale profiling [9909-134]
9909 3D Single detector stereo-SCIDAR for Mount Stromlo [9909-135]

9909 3E The statistics of atmospheric turbulence at Maunakea measured by RAVEN [9909-138]

9909 3F Characterisation of a turbulent module for the MITHIC high-contrast imaging testbed [9909-139]

9909 3G Vibrations in MagAO: resonance sources identification and first approaches for modeling and control [9909-141]

9909 3H AIR FLOW: airborne interferometric recombiner fluctuations of light at optical wavelengths [9909-144]

9909 3I Turbulence profiling for adaptive optics tomographic reconstructors [9909-146]

9909 3J SHIMM: a seeing and turbulence monitor for astronomy [9909-148]

9909 3K Closed-loop control for tip-tilt compensation on systems under vibration [9909-149]

9909 3L Vibrations in MagAO: frequency-based analysis of on-sky data, resonance sources identification, and future challenges in vibrations mitigation [9909-153]

9909 3M The bistatic geometry for Na profiling with LGS at Teide Observatory [9909-156]

9909 3N Simulation of an accelerometer-based feedforward vibration suppression in an adaptive optics system for MICADO [9909-157]

9909 3P William Herschel Telescope site characterization using the MOAO pathfinder CANARY on-sky data [9909-163]

9909 3R Atmospheric turbulence profiling using the SLODAR technique with ARGOS at LBT [9909-168]

9909 3S The study of variability of the atmospheric turbulence in the region Lake Baykal [9909-169]

POSTER SESSION: PATHFINDERS, NEW PROPOSED AO SYSTEMS AND CONCEPTS

9909 3U AO upgrade for VLT UT4: an 8m class HST from ground [9909-124]

9909 3V SOUL: the Single conjugated adaptive Optics Upgrade for LBT [9909-126]

9909 3X Empirical Green's function approach for utilizing millisecond focal and pupil plane telemetry in exoplanet imaging [9909-131]

9909 3Y Experimental results on using artificial neural networks for accurate centroiding in Shack-Hartmann wavefront sensors with elongated spots [9909-136]

9909 3Z SRAO: optical design and the dual-knife-edge WFS [9909-137]

9909 40 Analysis of wavefront reconstruction in 8-meter ring solar telescope [9909-140]
### Adaptive optics for high resolution spectroscopy: a direct application with the future NIRPS spectrograph [9909-142]

### Development of a novel three-dimensional deformable mirror with removable influence functions for high precision wavefront correction in adaptive optics system [9909-143]

### Getting ready for the first on sky experiment using an ELT-scaled elongated sodium laser guide star [9909-147]

### A testing facility at the Asiago Copernico telescope in the framework of the ADaptive Optics National laboratory of Italy: ADONI [9909-154]

### CHOUGH: implementation and performance of a high-order 4m AO demonstrator [9909-155]

### On the verification of NFIRAOS algorithms and performance on the HeNOS bench [9909-158]

### DRAGON-NG: a configurable and capable AO test-bench [9909-161]

### An engineered design of a diffractive mask for high precision astrometry [9909-167]

### Status of an extreme adaptive optics testbench using a self-referenced Mach-Zehnder wavefront sensor [9909-170]

### POSTER SESSION: ADVANCES IN AO CONTROL AND CALIBRATIONS

| 9909 4H | Natural guide-star processing for wide-field laser-assisted AO systems [9909-180] |
| 9909 4I | Green FLASH: energy efficient real-time control for AO [9909-183] |
| 9909 4J | Kaczmarz and Cimmino: iterative and layer-oriented approaches to atmospheric tomography [9909-188] |
| 9909 4K | The control switching adapter: a practical way to ensure bumpless switching between controllers while AO loop is engaged [9909-193] |
| 9909 4L | Dimensioning the MAORY real time computer [9909-194] |
| 9909 4M | Bridging FPGA and GPU technologies for AO real-time control [9909-197] |
| 9909 4N | Thirty Meter Telescope narrow-field infrared adaptive optics system real-time controller prototyping results [9909-202] |
| 9909 4P | Novel technology for reducing wavefront image processing latency [9909-206] |
| 9909 4Q | EDIFISE full-FPGA adaptive optics: first laboratory results using the IACAT optical ground support equipment [9909-212] |
| 9909 4R | Novel algorithm implementations in DARC: the Durham AO real-time controller [9909-215] |
| 9909 4S | Demonstration of the suitability of GPUs for AO real-time control at ELT scales [9909-217] |
| 9909 4V | Location-grouping algorithm based on limited actuators deformable mirror for high precision wavefront aberration correction in adaptive optics system [9909-221] |
| 9909 4W | Prediction control method to improve the dynamic performance of a close-loop adaptive optics system [9909-222] |

**POSTER SESSION: EXTREME AO**

| 9909 4Z | Speckle lifetime in XAO coronagraphic images: temporal evolution of SPHERE coronographic images [9909-174] |
| 9909 50 | High contrast imaging of exoplanets on ELTs using a super-Nyquist wavefront control scheme [9909-176] |
| 9909 52 | The path to visible extreme adaptive optics with MagAO-2K and MagAO-X [9909-184] |
| 9909 54 | Subaru Coronagraphic eXtreme Adaptive Optics: on-sky performance of the asymmetric pupil Fourier wavefront sensor [9909-189] |
| 9909 55 | Speckle nulling wavefront control for Palomar and Keck [9909-192] |
| 9909 56 | First on-sky closed loop measurement and correction of atmospheric dispersion [9909-196] |
| 9909 57 | Fast and robust exo-planet detection in multi-spectral, multi-temporal data [9909-199] |
| 9909 58 | Planet detection down to a few \( \lambda / D \): an RSDI/TLOCI approach to PSF subtraction [9909-200] |

**Part Three**

**POSTER SESSION: EXTREME AO (cont.)**

| 9909 59 | Focal-plane electric field sensing with pupil-plane holograms [9909-204] |
| 9909 5B | Precise wavefront control for stellar coronagraphy: possibilities by a common-path extremely unbalanced interferometer [9909-209] |

**POSTER SESSION: LASER GUIDE STAR SYSTEMS**

| 9909 5E | Comparison between observation and simulation of sodium LGS return flux with a 20W CW laser on Tenerife [9909-178] |
| 9909 5F | Polarization switching of sodium guide star laser for brightness enhancement [9909-179] |
| 9909 5G | LGS adaptive optics system with long-pulsed sodium laser on Lijiang 1.8 meter telescope 2014-2016 observation campaign [9909-182] |
POSTER SESSION: ASTRONOMY WITH AO

9909 SU The Robo-AO KOI survey: laser adaptive optics imaging of every Kepler exoplanet candidate [9909-226]
9909 SV GeMS/GSAOI performances from a user perspective [9909-228]
9909 SY High-z galaxies simulations: a benchmark for Global-MCAO [9909-234]

POSTER SESSION: WAVEFRONT SENSING

9909 SZ Optical solutions for accommodating ELT LGS wave-front sensing to small format detectors [9909-225]
9909 60 A general formalism for Fourier based wave front sensing: application to the pyramid wave front sensors [9909-227]
9909 61 Sensing wavefronts on resolved sources with pyramids on ELTs [9909-229]
9909 62 ESO adaptive optics NGSD/LGSD detector and camera controller for the E-ELT [9909-231]
9909 63 LIFT on Keck: analysis of performance and first experimental results [9909-233]
9909 64 Experimental study of an optimised Pyramid wave-front sensor for Extremely Large Telescopes [9909-235]
9909 65 Novel tip-tilt sensing strategies for the laser tomography adaptive optics system of the GMT [9909-236]
| 9909 66 | Comparative study of infrared wavefront sensing solutions for adaptive optics [9909-237] |
| 9909 67 | Pupil phase discontinuity measurement: comparison of different wavefront sensing concepts [9909-238] |
| 9909 68 | Correction of NIRI/Altair non-common path aberrations using focal plane sharpening [9909-239] |
| 9909 69 | Wavefront sensing using a photonic lantern [9909-240] |
| 9909 6A | High order dark wavefront sensing simulations [9909-242] |
| 9909 6B | Pyramid wavefront sensing using Laser Guide Star for 8m and ELT class telescopes [9909-243] |
| 9909 6C | A “Fast and Furious” solution to the low-wind effect for SPHERE at the VLT [9909-245] |
| 9909 6D | Estimating phase errors from pupil discontinuities from simulated on sky data: examples with VLT and Keck [9909-246] |
| 9909 6E | Exploring the operational effects of phase diversity for the calibration of non-common path errors on NIFRAS [9909-247] |
| 9909 6G | Fast modulation and dithering on a pyramid wavefront sensor bench [9909-249] |
| 9909 6H | PWFSs on GMCAO: a different approach to the non-linearity issue [9909-250] |
| 9909 6I | An achromatic low-order wavefront sensor [9909-251] |
| 9909 6J | Dark tip-tilt sensing [9909-252] |
| 9909 6K | Sparse aperture differential piston measurements using the pyramid wave-front sensor [9909-253] |
| 9909 6L | Laser guide star spot shrinkage for affordable wavefront sensors [9909-255] |
| 9909 6M | Solving the MCAO partial illumination issue and laboratory results [9909-256] |
| 9909 6N | Analytical expression of a long exposure coronagraphic point spread function [9909-258] |
| 9909 6P | Experimental result from tip-tilt measurement with a laser guide star at Yunnan Observatories [9909-260] |
| 9909 6Q | Correlation wavefront sensing for extended objects [9909-262] |
| 9909 6R | Development of an optical differentiation wavefront sensor based on binary pixilated transmission filters [9909-264] |
| 9909 6S | ZELDA, a Zernike wavefront sensor for the fine measurement of quasi-static aberrations in coronagraphic systems: concept studies and results with VLT/SPHERE [9909-265] |
| 9909 6T | Characterising latency for AO optical sensors: an implementation [9909-266] |
Low photon-count tip-tilt sensor [9909-267]

Fast gradient-based algorithm on extended landscapes for wave-front reconstruction of Earth observation satellite [9909-268]

The pyramid wavefront sensor used in the closed-loop adaptive optics system [9909-269]

POSTER SESSION: AO MODELING, ANALYSIS AND SIMULATIONS

Daytime turbulence profiling for EST and its impact in the solar MCAO system design [9909-270]

Comparison between simulations and lab results on the ASSIST test-bench [9909-277]

COMPASS: status update and long term development plan [9909-282]

Wavefront reconstruction with pupil fragmentation: study of a simple case [9909-287]

End-to-end simulations of the E-ELT/METIS coronagraphs [9909-290]

Simulations of E-ELT telescope effects on AO system performance [9909-298]

Pseudo-analytic simulation of woofer-tweeter MOAO system: application to MOSAIC [9909-301]

Accurate laser guide star wavefront sensor simulation for the E-ELT first light adaptive optics module [9909-304]

Preparation of AO-related observations and post-processing recipes for E-ELT HARMONI-SCAO [9909-305]

Deriving comprehensive error breakdown for wide field adaptive optics systems using end-to-end simulations [9909-307]

8s, a numerical simulator of the challenging optical calibration of the E-ELT adaptive mirror M4 [9909-309]

The numerical simulation tool for the MAORY multiconjugate adaptive optics system [9909-310]

Simulation of DKIST solar adaptive optics system [9909-311]

PASSATA: object oriented numerical simulation software for adaptive optics [9909-314]

Soapy: an adaptive optics simulation written purely in Python for rapid concept development [9909-315]

Analysis of the performances of 45 degrees tilted deformable mirrors for the EST MCAO [9909-318]
POSTER SESSION: POST-PROCESSING AO DATA

9909 7J The software package CAOS 7.0: enhanced numerical modelling of astronomical adaptive optics systems [9909-319]

POSTER SESSION: WAVEFRONT CORRECTORS

9909 7Y E-ELT M4 adaptive unit final design and construction: a progress report [9909-272]
9909 7Z Developments of piezo deformable mirrors [9909-275]
9909 80 GMTIFS: deformable mirror environmental testing for the on-instrument wavefront sensor [9909-276]
9909 82 Research on the optimization of a bimorph piezoelectric deformable mirror based on zeroth-order method [9909-292]
9909 83 Bimorph mirrors for adaptive optics in space telescopes [9909-294]
9909 84 Development of a miniaturized deformable mirror controller [9909-299]
9909 85 Fault-tolerant drive electronics for a Xinetics deformable mirror at GeMS DM0 [9909-321]
Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Abicca, R., 2D
Absil, Olivier, 20, 22, 73
Adamkovics, Mate, 05
Adler, Tobias, 2L
Agapito, Guido, 15, 1B, 2D, 3V, 6B, 6K, 7B, 7E
Akiyama, M., 10, 3E
Alaluf, D., 83
Albrecht, Alexander R., 5R
Adamkovics, Mate, 05
Albrecht, Alexander R., 5R
Allain, Guillaume, 6I
Aller-Carpentier, Emmanuel, 2S, 2Z
Allington-Smith, Jeremy, 69
Alonso, Ángel, 3M, 4Q
Alvarez, Domingo, 12
Ambrosino, Filippo, 5L, 7P
Ammons, S. Mark, 0V, 2F, 4E
Amorim, A., 2M
Amram, Philippe, 0P
Andersen, David R., 05, 06, 07, 0L, 10, 1G, 34, 3E, 49, 6D, 6E
Andersen, Morten, 1S
Andrighettoni, Mario, 4I, 7Y
Antichi, J., 1B
Antonini, Tania, 7Z
Antoshkin, L. V., 32
Araujo Hauck, Constanza, 2F
Arcidiacono, Carmelo, 2D, 3V, 4J, 4L, 6A, 6J, 6K, 6M, 77, 7B
Argomedo, Javier, 02, 2H, 2S, 2Z
Artib, Tarik, 7Z
Armut, Lee, 05
Arriola, Alexander, 0W, 33
Arsenault, Robin, 02, 1U, 2H, 2S, 2Z, 62
Asensio Ramos, A., 1H
Ashby, Dave, 03, 1T
Atkinson, D., 0C
Atkinson, Dani E., 18, 5U
Atwood, Jenny, 34
Aubry, Marie, 7Z
Baba, Naoshi, 2N
Baccicatt, Francesca, 31
Baffa, Carlo, 31
Bailey, Vanessa P., 0V
Baker, Ian, 12, 13
Ball, Jesse G., 68
Banas, T., 4Z
Bao, Hua, 19, 2C, 2I
Baranec, Christoph, 02, 0F, 1A, 5U
Barberio, Michael J., 8S
Bardou, Lisa, 44
Barr, David, 4P
Barth, Aaron, 05
Bartos, R., 0D
Baruffolo, Andrea, 0U, 1B, 27, 2D, 31, 4J, 4L
Bastidas, Alastair G., OC, 1L, 1Q, 3P, 44, 4B, 4P, 4R, 4S
Bastia, R., 83
Bastard, Arnaud, 7Z
Baudouin, Pierre, 0A, 0U, 20
Bazzon, Andreas, 27
Beaufort, Emmanuel, 7Z
Béchet, Clémentine, 5K
Bechter, Andrew, 2X
Becher, Eric, 2X
Belkov, Ruslan, 84
Bellazzini, Michele, 06, 2D
Bello, D., 1C, 5E
Benda, izu, 4E, 84
Benetti, Stefano, 47
Benneke, B., 0D
Bennet, Francis, 11, 1X, 3D, 6T
Bento, J., 0W
Berdja, Amokrane, 3Y
Bergomi, Maria, 31, 47, 5Y, 6A, 6H, 6J, 7Q
Berkefeld, Thomas, 24, 29
Bernard, André, 1S
Bernard, Julien, 4I, 4M
Berrill, Francesco, 7I
Bertero, Mario, 77
Bertram, Thomas, 0B, 61, 6M
Berwein, J., 6M
Beuzit, Jean-Luc, 0U, 16, 27, 4Z, 6C, 6S
Bezumyannikova, Yulia, 5B
Bharmal, Nazim Ali, 30, 48, 4B
Bian, Qi, 42, 4V
Bian, Qi, 5G
Biasi, Roberto, 4I, 7Y
Biliotti, F., 1B, 2D
Bionti, Federico, 47, 5Y
Bilanc, Urban, OC, 4B, 4I, 4R, 4S
Black, Martin, 4B
Blair, C., 1B, 68
Blanchard, P., 6S
Blanco, Leonardo, 09, 78
Blind, N., 41
Bloxham, G., 80
Bo, Yong, 5G
Boccacci, Patrizia, 7T
Deen, Casey, 2L, 2M
Defrère, Denis, 22
de Haan, Menno, 27
Dekany, Richard, 0D, 15, 55
Delabre, B., 22
Delacroix, Christian, 22, 73
Delboulbé, A., 2D
Del Moro, Dario, 7I, 7P
Delplancke, Francoise, 2L, 2M
Del Vecchio, C., 2D
Delvit, J. M., 6V
Dembet, R., 4I
Demidov, M. L., 32
Deneux, H., 4I
Deng, Jijiang, 5G
Deng, Keran, 5G
Denis, Loïc, 57, 7N
Dennison, Kaitlin, 4E
Densmore, Adam, 34
De Pascale, Marco, 2D, 31
De Rosa, A., 2D
De Rosa, Robert J., 0V
Devanney, Nicholas, 1R, 57, 7W
Deysenroth, M., 36
Diddle, S., 66
Dérie, Frédéric, 1N
Dilla, Marco, 31, 47, 5Y, 6A, 6H, 6J
Dillal, Emiliano, 06, 0A, 2D, 4L, 77, 7B
Dipper, Nigel A., 0C, 4B, 4I, 4P, 4S
Di Rico, G., 1B, 2D
Dixon, Thomas, 6T
Do, Tuan, 05, 1P
Doelman, Niek, 1M
Dohlen, Kjell, 09, 0U, 16, 27, 37, 3F, 67, 6C, 6L, 6S, 78
Dominik, Carsten, 27
Donahue, Jeff, 2F
Donaldson, Robert H., 02, 1U, 2H, 2S, 22
Dong, Ruoxi, 5G
Donini, Michele, 4J
Doppmann, Greg, 0S
D’Orazio, Valentina, 31, 7Q
d’Orgeville, Céline, 0R, 1X, 2F
Doerr, Christophe, 6R
Doucet, Nicolas, 0A, 4L, 71
Doughty, D., 0W
Downing, Mark, 0U, 14, 18, 27, 2H, 62
Dubilek, Mark, 0Y
Dubbeldam, Cornelis Marc, 1N, 30, 48, 4B
Duev, Dmitry, 1A
Dufourcq, G., 4I
Duhouin, Philippe, 2S
Dumas, Christophe, 05
Dunlop, Colin, 4B
Dunn, Jennifer S., 05, 4N
Dupuy, Christophe, 12

Durand, Sébastien, 0A
Durney, O., 3V
Dufey, Gabrielle, 7Z
Dzuluban, Ilia, 5B
Ebert, Monica, 2L
Echeandia, Carlos, 4Q
Edger, S., 1B
Eisenhauer, Frank, 2L, 2M
El Hadi, Kacem, 09, 3F, 64, 67, 6L, 78
Ellerbroek, Brent L., 05, 08, 4N, 5Q
Elsijwik, Eddy, 27
Emaleev, O. N., 32
Emoli, Ilaria, 7I
Escarate, Pedro, 3G, 3K, 3L, 5M
Espeland, B., 80
Esposito, Simone, 01, 0A, 15, 1B, 2D, 2E, 2G, 31, 36, 3R, 3U, 3V, 4L, 52, 68, 6H, 77, 78, 7E
Esselborn, Michael, 2L, 2M, 75
Fan, Muwen, 5Q
Fan, Tingwei, 5F
Fan, Xinlong, 19, 1D, 2I
Fantinel, Daniela, 2D, 31
Farinato, Jacopo, 31, 47, 4J, 5Y, 6A, 6H, 6J, 7Q
Farisato, Giancarlo, 31
Fauvarque, Olivier, 60, 64
Feautrier, Philippe, 0A, 0C, 13, 2D, 44, 4L, 77, 7B
Pedrigo, E., 2Y
Feger, T., 0W
Feldt, Markus, 08, 61, 73
Fennia Castellà, Bruno, 20, 22, 25, 55, 63
Feng, Yan, 5F
Feng, Zhongyi, 2I
Ferrari, André, 57
Ferrari, Marc, 6L
Ferraro, Francesco R., 5V
Ferraro, Ivan, 06
Ferreira, Florian, 0A, 4I, 71, 79
Ferruzzi, D., 2D
Fetzner, Gregory J., 0R
Finger, Gert, 12, 14, 2L
Fin, Luca, 01, 2D, 3B, 3V
Fiorentino, Gianluca, 06, 07, 1G, 2D
Fischer, Andreas, 24
Fitzgerald, M., 0D, 1P
Fitzsimmons, Joeleff, 34
Fitzsimons, Ewan, 1I
Flaischer, A., 4I
Folcher, Jean-Pierre, 7J
Foley, Michael, 2X
Follet, Katherine B., 01, 0V
Fontana, A., 2D
Foppiani, Italo, 2D, 4L, 7B
Forsberg, Pontus, 73
Fortney, J., 0D
Frahm, R., 2Y
Frazin, Richard A., 3X
Frolov, Pavel, 47
Frolov, Pavel, 5B
Frigo, Aldo, 47
Fucik, J., 0D

Proc. of SPIE Vol. 9909 990986-19
Fuensalida, Jesús J., 3M, 4Q
Fumi, Pierluigi, 7Y
Fusco, Thierry, 09, 0U, 15, 16, 1I, 1Q, 1S, 1U, 37, 3C, 3F, 3P, 4H, 4Z, 60, 63, 64, 66, 6L, 65, 78
Gach, Jean-Luc, 09, 0C, 0P, 13, 44, 6L
Gaessler, Wolfgang, 31, 36
Gago, F., 2Z
Galicher, R., 4Z
Gallie, A. M., 09
Gallieni, Daniele, 7Y
Gamroth, D., 10, 3E
Gao, Yang, 5G
Garbellotto, Chiara, 4J
Garcés Santibañez, Eduardo, 3Y
Garcés, Javier, 3G, 3K, 3L, 5M
Gardiner, John, 02
Garrel, Vincent, 1X, 2F, 4E
Gaudi, Scott, 1Y
Gavel, Donald T., 2W
Geisler, Douglas, 5V
Gemperlein, H., 36
Gendron, Éric, 0A, 0C, 1I, 1Q, 2L, 2M, 3I, 3P, 44, 4I, 5Z, 71, 76, 79
Geng, D., 4I
Gerard, Benjamin L., 50, 58
Ghez, Andrea M., 05, 1P
Ghigo, M., 2D
Giallongo, Emanuele, 31
Gigoux, Pedro, 2F
Gilles, Luc, 4N
Giordano, C., 1B, 2D, 6B
Girard, Julien H. V., 0U, 16, 42, 6S
Giraut, Orion, 60
Gluck, L., 2D
Gluck, Martin, 3N
Goebel, Sean B., 01, 2E, 6M
Gonzalez Gonzalez, Carlos, 22
Gong, Mali, 42, 4V
Gonte, Frederic, 2L, 2Y
González-Núñez, Héctor, 5K
Goode, Phil, 29
Goodwin, Michael, 33
Gorcheix, Nicolas, 29
Goovaert, Alain, 27
Gratadour, Damien, 0A, 0C, 1G, 1Q, 44, 4I, 4M, 51, 76, 79
Greffe, Timothee, 13
Greggio, Davide, 31, 47, 5Y, 6A, 6H, 7Q
Grézes-Besset, Catherine, 7Z
Grigoriev, V. M., 32
Groënink, Denis, 7Z
Groff, T., 0W
Gross, Simon, 0W, 33
Grosse, Doris, 3D
Gu, Naiting, 2I
Gu, Chunlin, 19, 1D
Guan, Yuming, 19, 1D, 2I
Guenter, Olivier, 0D, 0J, 0W, 15, 18, 31, 4E, 52, 54, 56, 7K
Guzmán, Christian, 3Y
Habraken, Serge, 73
Hackenberg, W., 02, 5E
Hackett, Shawn, 5R
Halfert, S., 21
Hagelberg, J., 0W
Haguenauer, Pierre, 16, 2H, 2M, 2S, 2Y
Hall, Donald N. B., 0D, 15, 18
Halsall, Rob, 4P
Hamer, Francois, 1I
Hammersley, P., 09
Hanaka, Yoihiro, 2N
Hanley, Kenneth, 1R, 7W
Hao, Lei, 05
Harris, Robert J., 69
Hart, Michael, 5N
Hayano, Yutaka, 02, 05, 56
Hayashi, M., 0W
Hayward, Thomas, 0V
Heidecke, Frank, 24
Hénault, F., 2D
Henning, Thomas, 2L, 2M
Henry, David M., 09, 0C, 48
Herbst, T. M., 2E, 6M
Herrald, Nick, 11, 1X
Herriot, Glen, 0L, 1J, 1Z, 34, 49, 4N, 6G
Herscovici-Schiller, Olivier, 6N
Hibon, Pascale, 2H
Hill, Alexis, 34
Hill, J. M., 2E
Hinz, Philip M., 01, 2E, 2X, 31, 3V, 52
Hippler, Stefan, 0B, 2L, 61, 73
Hölk-Santibanez, Daniel, 30, 48
Holzlöhner, Ronald, 5E, 5P
Horodincu, M., 83
Hu, Lin, 82
Hu, R., 0D
Hu, R., 2D
Huang, Jiayin, 3G
Huang, Kai, 6P
Huang, Lei, 42, 4V
Huber, Armin, 2L, 2M
Hubert, Zoltan, 0A, 2L, 2M
Hubin, Norbert, 0U, 27, 2Z
Hube, Elsa, 20, 22, 55, 73
Hudepohl, G., 2T
Huet, J.-M., 0C
Hugot, Emmanuel, 09, 0U, 6L
Hunter, L., 0F
Hyde, Elizabeth, 84
Iannicola, Giacinto, 06
Norris, Barnaby, 0J, 0W, 33
Núñez Cagigal, M., 1C, 35
Obereder, Andreas, 0B, 61
Oberti, Sylvain, 0Z, 1U, 2D, 2L, 2M, 2S, 2Z, 6Z, 7B
Oh-ishi, Akira, 2N
Okita, Hirofumi, 0J
O'Neal, Jared, 16
Ono, Y. H., 10, 3E, 3P
Onuma, Eleanya E., 2X
Orban de Xivry, G., 36
Origlia, Livia, 5V
Osborn, James, 0C, 0H, 1M, 1N, 3C, 3I, 3J, 44
Otarola, Angel, 0S
Ott, Jürgen, 2L
Otten, Gilles, 52, 73
Ouattara, Issa, 0P
Oya, Shin, 02, 10, 3E
Pagano, Isabella, 2X
Pagès, Hubert, 7Z
Palazzari, P., 4I
Palmer, David W., 0V
Palomo, Richard, 7T
Pandey, Shashi B., 05
Panduro, Johana, 2L, 2M
Pareschi, G., 2D
Pariani, Giorgio, 7A, 7Y
Pascal, Sandrine, 09, 6L
Patauner, Christian, 4I, 7Y
Pathak, Prashant, 0W, 56
Patt, Mauro, 2D, 77, 7B
Paulin, Nicolas, 1X
Pepe, F., 41
Perera, Saavidra, 0H, 3J
Perraud, L., 6v
Perraut, C., 2M
Perrot, Denis, 0C, 4I, 4M
Perin, G., 2M
Perin, Marshall D., 0V
Perrot, Clément, 0A
Peruchon-Monge, Ulysse, 7J
Pescoller, Dietrich, 4I, 7Y
Peter, D., 36
Petit, Cyril, 09, 0U, 1I, 4H, 4K
Pettazzi, Lorenzo, 2M, 2Y, 7Y
Pfrommer, Thomas, 44, 5E
Phillips, Andrew C., 0S
Pietrow, A. G. M., 21
Pinna, Enrico, 01, 1B, 2G, 31, 3V, 52, 6B, 6H, 7Q
Piqueras, Laure, 78
Plana, Henri, 1S
Plantet, Cedric, 15, 63, 66
Pluzhnik, Eugene, 84
Por, Emiel H., 59
Porta, F., 4I
Portaluri, Elisa, 47, 5Y, 6H
Postnikova, M., 3F
Pött, Jörg-Uwe, 1G, 3N
Poyneer, Lisa A., 0V, 2W
Pragl, Johann, 27
Prato, Marco, 7T
Prebet, D., 4I
Preumont, A., 83
Price, Ian, 11, 1X, 6T, 80
Prieto, G., 1C
Puech, M., 71
Pueyo, Laurent, 6L
Puglia, Marta, 1C, 4Q
Puget, Pascal, 27, 6S
Puglisi, Aifio, 01, 1B, 2D, 2G, 31, 36, 3V, 52, 6B, 7B, 7E, 7Q
Qiao, Jie, 6R
Quentin, J., 2Z
Quiros-Pacheco, F., 1T
R. Santhakumari, K. K., 6M
Raab, W., 36
Rabaud, Didier, 64
Rabien, S., 2E, 36
Rabou, P., 2D
Ragazzoni, Roberto, 2D, 31, 47, 4J, 5Y, 6A, 6H, 6J, 6M
Ragland, Sam, 0S, 1P, 25, 63
Rahmer, Gustavo, 03, 2E, 2G, 36
Rains, A., 0W
Rajan, Abhijith, 0V
Ramos, Jose, 2L, 2M
Rampy, Rachel, 25, 63
Ramsay, Suzanne, 14, 2D
Rantakyrö, Fredrik T., 0V
Rao, Changhui, 19, 1D, 2C, 2I, 5G, 5Q, 6W
Rao, Xuejun, 19, 2C, 2I
Raynaud, Henri-François, 0M, 4K
Rebeschini, Mauro, 47
Reeves, Andrew P., 0C, 3I, 44, 4B, 7F
Reggiani, Maddalena, 22
Reiner, C., 2Y
Reyes García-Talavera, M., 1C, 3M, 5E
Reyes-Moreno, Javier, 14, 1B, 2H, 62
Reynolds, Robert O., 2X
Riccardi, Armando, 01, 0A, 1B, 2D, 3V, 52, 7A, 7Y
Ricciardi, A., 5L
Ricciardi, S., 2D
Richards, Kit, 0Y
Richards, Samuel, 33
Richey, Jeff W., 5R
Riddle, Reed, 0F, 1A, 5U
Rigaut, François, 11, 15, 1X, 2F, 3D, 6T, 80
Rimmele, Thomas, 0X, 0Y, 29
Riquelme, Miguel, 2L
Ritchie, I., 11
Riva, M., 2D
Robert, C., 66
Robertson, David J., 48
Rochat, S., 2D
Rochester, Simon, 5E, 5P
Rodeghiero, Gabriele, 1G
Rodrigues, Myriam, 1I
Rodríguez-Ramos, Luis F., 1C, 35, 4Q
Roelfsema, Ronald, 27
Rohloff, Ralf-Rainer, 2L, 2M
Rojas Zagals, Diego, 3G, 3K, 3L, 5M
Rolt, Stephen, 4B
Rosado, M., 1C
Rosensteiner, Matthias, 1J, 49
Rouaud, C., 4I
Roussel, F., 2D
Rousset, Gérard, 0A, 0C, 1I, 1Q, 2L, 3P, 44, 4I, 76, 79
Roux, A., 2D
Ruane, Garreth, OD, 73
Rudy, Alexander R., 2W
Rui, Daoman, 5Q
Rudy, Alexander R., 2W
Rui, Daoman, 5Q
Runburg, Elliott, 2X
S. Béjar, V. J., 1C
Saathof, Rudolf, 6U
Salama, Maïssa, 1A
Salasnich, Bernardo, 0U, 27, 2D, 31
Salgado, F., 2T
Samati, Manash, 1S
Sanft, Shane, 02
Saracco, P., 2D
Saracino, Sara, 5V
Sarazin, Marc, 0H, 1N
Saunter, Christopher D., 6Q
Sauvage, Jean-François, 09, 0U, 16, 1U, 27, 37, 3C, 3F, 4H, 4Z, 56, 64, 67, 6C, 6D, 6E, 6L, 6N, 6S
Savransky, Dmitry, 0V
Sawodny, Oliver, 3N
Saxenhuber, Daniela, 0B
Schellhauer, Silvia, 0B, 2L, 2M
Schitter, Georg, 6U
Schmid, Hans Martin, 0U, 27
Schmidt, Dirk, 0X, 24, 29, 7C
Scholl, Jürgen, 48
Schnetler, Hermine, 09, 78
Schoeck, Matthias, 05
Schreiber, Laura, 06, 0A, 1G, 2D, 4L, 77, 7B
Schubert, Josef, 0A
Schuhler, Nicolas, 2L
Schwab, C., 0W
Schwarz, Noah, 09, 4P, 78
Schweinsberg, Aaron, 6R
Schwerer, G., 0W
Sedighi, B., 2Z
Sekulic, Predrag, 0Y
Serabyn, Eugene, 0D, 0W, 20, 22, 55, 7K
Service, Max, 02
Sevin, Arnaud, 0A, 0C, 0U, 4I, 4M, 71, 76
Sharp, R., 80
Shchukinova, Inna, 5B
Sheik-Bahae, Mansoor, 5R
Shen, Yu, 5G
Shikhovtsev, A. Yu., 32, 3S
Siebenmorgen, Ralf, 2H
Simard, Luc, 05
Simmons, Julia, 22
Singh, Garima, 0J, 0W, 7K
Sinquén, Jean-Christophe, 7Z
Skarski, B., 1P
Sivitilli, A., 36
Sivo, Gaetano, 1X, 2F, 4E
Skemer, A., 0D
Smith, C., 11
Smith, Malcolm, 4N
Snik, Frans, 21, 52
Soenke, Christian, 0U, 1B, 1U, 2H, 2S, 2Z
Solar, Mauricio, 5M
Sollau, Dirk, 24
Sosa, Richard, 03
Soulez, Ferréol, 7N
Spanó, Paolo, 1B, 3U, 7A
Spavone, M., 2D
Srinath, Srikar, 2W
Stadler, Eric, 0C, 13, 2D, 44
Stangalini, Marco, 31, 7I, 7P, 7Q
Steele, Brad, 02
Stegmeier, Jörg, 12
Stetson, Peter B., 06, 07
Stormski, Paul J., Jr., 25, 5J
Sturm, J., 36
Stroumbi, G., 2M
Ströbele, Stefan, 0O, 2S, 2Z
Stuijk, Remko, 0B, 1G, 61
Suárez Valles, Marcos, 0U, 0Z, 1B, 1U, 2L, 2M, 2S
Suh, J., 36
Sung, Sangchul, 07
Subramaniam, Annappuri, 05
Subramanian, Smitha, 05
Surdej, Jean, 73
Suzuki, Ryuji, 05
Sy, Adama, 7J
Szapudi, I., 0F
Takami, H., 0W, 56
Takamiya, M., 0F
Takato, N., 0W
Talbot, Robert Gordon, 0C, 44, 48
Tallon, Michel, 1H, 4F, 72
Tamura, M., 0W
Tan, Jonathan C., 05
Tang, Jinlong, 5Q
Tang, Zhengan, 6K
Taylor, Gregory E., 03, 2E, 2G
Tecza, M., 09
Tenegi, F., 1C
Terai, Tsuyoshi, 05
Testa, Vincenzo, 06
Thalhatte, Niranjan, 09, 4H, 78
Thibault, Simon, 02, 2V, 61
Thiebaut, C., 6V
Thiébaut, Éric, 1R, 4F, 57, 7N, 7W
Thomas, Jim, 5J
Thomas, Sandrine, 0V
Thomson, Robert R., 69
Thorn, Elliott, 3D
Tintori, Matteo, 7A, 7Y
Todd, S., 0C
Takovinin, Andrei, 3Z
Tolstoy, Eline, 06, 1G
Tomasella, Lina, 47
Tonry, J., 0F
Toomey, Douglas, 02
Tordo, Sebastien, 2H, 2Z
Torroni, Paolo, 4L
Townson, Matthew J., 3I, 6Q
Tran, Hien, 22
Traverso, Luciano, 47
Treu, Tommaso, 05
Trifonov, V. D., 32
Trujillo, Chadwick A., 1X, 2F, 68
Tsubota, Kevin, 0S
Tubío Araujo, O., 1C, 35
Tully, R. B., 0W
Turatto, Massimo, 47
Turci, Alessio, 0I, 38, 3B
Turri, Paolo, 06, 07, 1G, 49
Tuthill, P., 0W
Ueno, Satoru, 2N
Uhlendorf, Kristina, 1X
Valenzuela, Jose Javier, 2H, 2S, 37
van Dam, Marcos A., 1P, 25, 2F, 65, 6D
van Kooten, Maaike, 1J, 6G
Vargas Catalan, Ernesto, 22, 73
Vasishth, G., 0D
Vassallo, Daniele, 31, 47, 6A, 7Q
Vega Reyes, N., 6X
Veillet, C., 2E
Venessa, Lars, 08
Ventura, N., 2D
Vérin, Jean-Pierre, 06, 07, 0L, 0V, 1J, 1Z, 2V, 49, 4N, 6D, 6E, 6G, 6I
Verdoes Kleijn, Gijs, 1G
Vérinaud, Christophe, 09, 2D, 31, 71, 7Q
Vernet, Elise, 00, 02, 2S, 7Y
Verheijen, Arjen, 09, 22, 3U, 4H
Vezilj, Jennifer, 01
Vick, Andy, 4P
Vidal, Fabrice, OA, 0C, 1Q, 3I, 3P, 44, 71
Vigan, Arthur, 0U, 16, 3F, 4Z, 6D, 6S
Viletta, R., 35
Viotto, Valentina, 31, 47, 5Y, 6A, 6H, 6J, 7Q
Vogel, Conrad, 03
Vola, Pascal, 09, 6L
Wahaj, Zahed, 42
Wallace, J. K., 0D
Walther, Gregory, 05
Wang, Chaoyan, 6K
Wang, Cheng, 2I
Wang, Haiwen, 82
Wang, Hongyan, 5O
Wang, J., 0D
Wang, Jason J., 0V
Wang, K., 83

Wang, Lianqi, 0L, 4N, 5Q
Wang, Pengyuan, 5G
Wang, Shengqian, 19, 6W
Wang, Xiaoyun, 2I
Wang, Zhiyong, 2I
Wei, Kai, 0S
Wei, Kai, 19, 1D, 5G, 5Q, 6W
Wei, Ling, 1D, 5G
Weinberger, Alycia, 52
Weiss, Jason L., 05
Weller, Harald J., 12
Wertz, Olivier, 22
Wetherell, Ed, 0S
White, John, 68
Wilby, M. J., 21, 6C
Wildi, Francois, 27, 41
Wilson, Richard W., 0H, 1N, 3I, 3J
Wincentzen, James, 05
Withington, Kanao, 3H
Witzel, G., 1P
Wizinowich, Peter, 0D, 0S, 15, 16, 1P, 22, 25, 63, 6D
Wöger, Friedrich, 0X, 0Y, 29
Wolfe, J., 2Y
Wong, Michael, 05
Woodward, Charles E., 2X
Wright, Shelley A., 05, 0F
Wu, Ya-Lin, 01
Xi, Fengjie, 5O
Xian, Hao, 19, 1D, 5Q
Xiong, Yaoheng, 6P
Xompero, Marco, 01, 1B, 2D, 3V, 52, 7A, 7B, 7Y
Xu, Xiaojun, 5O
Xu, Zuyan, 5G
Yan, Meng, 4V
Yan, Zhao-jun, 4W, 6K
Yang, Zhou, 5R
Yao, Ji, 5G
Younger, Eddy J., 0C, 48, 4B, 4I
Zavagno, Annie, 1S
Zerbi, F. M., 2D
Zhai, Dongsheng, 6P
Zheng, Jessica, 33
Zheng, Lixin, 6K
Zheng, Wenjia, 5G, 6W
Zhong, Libo, 2I
Zhou, Chenlu, 42, 4V
Zhou, Longfeng, 1D
Zhou, Luchun, 19, 1D, 5G
Zhou, Tianhua, 5F
Zhou, Yu, 5G
Zhu, Lei, 19, 2C, 2I
Zhu, Liyun, 6K
Zhu, Nenghong, 6K
Ziad, Aziz, 1K
Ziegleder, J., 36
Ziegler, Carl, 3Z, 5U
Zins, Gérard, 0A, 2L, 2M, 6S
Zúñiga, Sebastián, 3G, 3K, 3L, 5M
Zuo, Junwei, 5G
Conference Committee

Symposium Chairs

Colin Cunningham, UK Astronomy Technology Centre
(United Kingdom)
Masanori Iye, National Astronomical Observatory of Japan (Japan)

Symposium Co-chairs

Allison A. Barto, Ball Aerospace & Technologies Corporation
(United States)
Suzanne K. Ramsay, European Southern Observatory (Germany)

Conference Chairs

Enrico Marchetti, European Southern Observatory (Germany)
Laird M. Close, The University of Arizona (United States)
Jean-Pierre Véran, National Research Council Canada (Canada)

Conference Program Committee

Christoph Baranec, University of Hawai‘i (United States)
Antonin H. Bouchez, GMTO Corporation (United States)
Celine D’Orgeville, The Australian National University (Australia)
Brent L. Ellerbroek, Thirty Meter Telescope Observatory Corporation
(United States)
Simone Esposito, INAF - Osservatorio Astrofisico di Arcetri (Italy)
Thierry Fusco, Laboratoire d’Astrophysique de Marseille, ONERA
(France)
Olivier Guyon, The University of Arizona (United States)
Yutaka Hayano, National Astronomical Observatory of Japan
(Japan)
Caroline Kulcsar, Institut d’Optique (France)
Anne-Marie Lagrange, Institut de Planétologie et d’Astrophysique de
Grenoble (France)
Jessica R. Lu, University of Hawai‘i (United States)
Bruce A. Macintosh, Stanford University (United States)
Pierre-Yves Madec, European Southern Observatory (Germany)
Elena Masciadri, INAF - Osservatorio Astrofisico di Arcetri (Italy)
Claire E. Max, University of California, Santa Cruz (United States)
Richard M. Myers, Durham University (United Kingdom)
Laura Schreiber, INAF - Osservatorio Astronomico di Bologna (Italy)
Dirk Soltau, Universität Freiburg (Germany)
Mitchell Troy, Jet Propulsion Laboratory (United States)
Elise Vernet, European Southern Observatory (Germany)
Peter L. Wizinowich, W.M. Keck Observatory (United States)

Session Chairs

1 Status of Current AO Projects I
Enrico Marchetti, European Southern Observatory (Germany)

2 Astronomy with AO I
Laird M. Close, The University of Arizona (United States)

3 AO for the ELTs
Antonin H. Bouchez, GMTO Corporation (United States)

4 Pathfinders, New Proposed AO Systems, and Concepts I
Simone Esposito, INAF - Osservatorio Astrofisico di Arcetri (Italy)

5 Characterization, Measurement and Modeling of the Disturbances Faced by AO I
Thierry Fusco, Laboratoire d'Astrophysique de Marseille, ONERA (France)

6 Advances in AO Control and Calibrations I
Richard M. Myers, Durham University (United Kingdom)

7 Wavefront Correctors
Elena Masciadri, INAF - Osservatorio Astrofisico di Arcetri (Italy)

8 Laser Guide Star Systems
Claire E. Max, University of California, Santa Cruz (United States)

9 Extreme AO I
Olivier Guyon, The University of Arizona (United States)
Bruce A. Macintosh, Stanford University (United States)

10 Status of Current AO Projects II
Dirk Soltau, Universität Freiburg (Germany)
Yutaka Hayano, National Astronomical Observatory of Japan (Japan)

11 Wavefront Sensing I
Christoph Baranec, University of Hawai‘i (United States)

12 Extreme AO II
Mitchell Troy, Jet Propulsion Laboratory (United States)
13 Status of Current AO Projects III
Pierre-Yves Madec, European Southern Observatory (Germany)
Peter L. Wizinowich, W.M. Keck Observatory (United States)

14 Astronomy with AO II
Anne-Marie Lagrange, Institut de Planétologie et d’Astrophysique de Grenoble (France)

15 Pathfinders, New Proposed AO Systems, and Concepts II
Jessica R. Lu, University of Hawai’i (United States)

16 Characterization, Measurement, and Modeling of the Disturbances Faced by AO II
Elena Masciadri, INAF - Osservatorio Astrofisico di Arcetri (Italy)

17 Post-processing AO Data
Brent L. Ellerbroek, Thirty Meter Telescope Observatory Corporation (United States)

18 Advances in AO Control and Calibrations II
Laura Schreiber, INAF - Osservatorio Astronomico di Bologna (Italy)

19 Wavefront Sensing II
Laura Schreiber, INAF - Osservatorio Astronomico di Bologna (Italy)