Latest AO simulation results for the E-ELT

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ABSTRACT

In this paper, we present the latest AO simulation results done at ESO in the context of the E-ELT. We present an analysis of a potential failure mode (a broken concentrator, which tilts a group of 7 segments). We look at the behavior of a cascaded AO system, where a low order system is fed into a high order AO system, in the context of PCS, the future planet finder system for the E-ELT. We then investigate what happens if we do not use modulation at all an infra-red pyramid sensor (in the framework of METIS). Finally, some very preliminary points are investigated about natural guide star sensing in a tomographic AO system.

Keywords: Pupil fragmentation, wavefront sensing, Pyramid wavefront sensor

1. INTRODUCTION

We present here some AO simulation results done for the E-ELT. They do not represent a finished analysis, but rather present the status of various simulation activities that have been carried out in the last year. The show both activities on the telescope itself, as more instrumentation focused activities.

2. ELT SEGMENT CONCENTRATOR FAILURE

We investigate what happens when a segment concentrator fails on the ELT. If this failure mode happens, a group of 7 segments are slowly tilted simultaneously, as shown in the figure below. From a hardware point of view, the main mirror (M1) Segment Subunit control is organized by groups of 7 segments (Segment Flowers), i.e. all control electronics of a segment flower is hosted within one control cabinet (Segment Concentrator). Therefore, failure patterns could affect full flowers, i.e. groups of 7 segments. We investigate both the spatial and temporal behaviour of this failure, as a time series of the position of the segments is provided. In it, the amount of tilt of the segments increases linearly with time, to reach 3.5um PV (wavefront) after 20s.

The figures show that the shape of the phase input at the end of the time series, with the clump of tilted segments. The difference in the shape of the adaptive M4 mirror, without and with the tilted segments, at the end of time series, and the time evolution of the Strehl ratio of the AO system, while the segments are slowly drifting towards their final tilted position. The command matrix is not aware the segments are tilted.

Clumped tilted segments do not introduce AO loop instability here. Performance is affected, but not hugely. The temporal behaviour of concentrator failure is not critical (in the presented case). But: no adaptive M4 stroke limits were introduced and its temporal behaviour was not simulated.

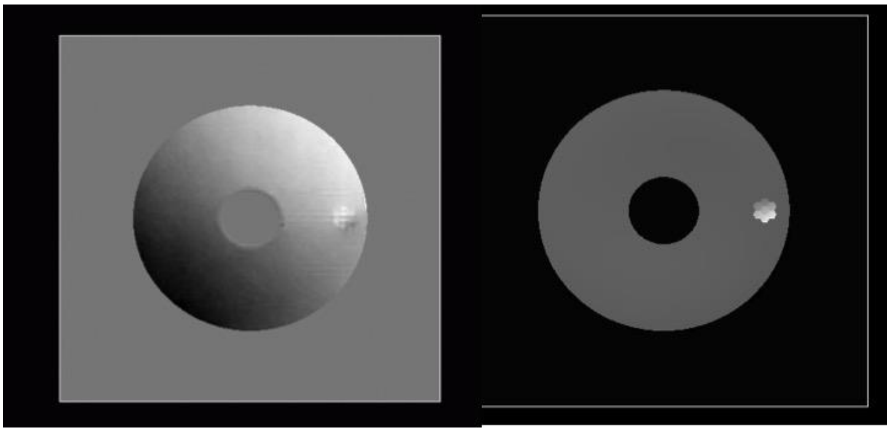

Figure 1: On the left, difference between the DM shapes with and without the tilted segments. On the right, shape of the phase screen with tilted segments.

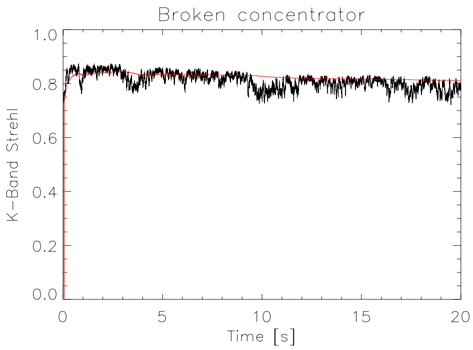

Figure 2: Strehl as a function of time, when the concentrator breaks and slowly tilts towards its final position.

3. DUAL STAGE XAO BEHIND M4 (FOR PCS & DM DEV.)

We explore the behaviour of two cascaded AO systems, working separately, to produce an XAO correction aimed at high contrast imaging of exo-planets. The idea is to first use a standard SCAO system (in our case, the adaptive M4 of the ELT and an associated 74x74 sub-aperture SH sensor) to correct the “low” orders (first ~2000 modes). Completely independently of this first system, downstream, another AO system runs a higher order DM, with 148x148 sub-apertures. In this scheme, the XAO system’s DM requires much less stroke (once the system has converged, see below) than an XAO system seeing all the turbulence. The M4 was simulated with its actual geometry, the XAO mirror has a square (Fried) geometry. The advantage of this setup is simplicity, as the first stage can be designed and implemented and tested completely independently of the second system. The first system could for example be a clone of a first generation SCAO system, and so could be a result of “recycling”, considerably reducing cost of the full system. It also reduces the complexity, as the interaction between the two systems are minimized.

In this first proof of concept simulation, both AO systems are based on Shack-Hartmann. In the final system, the highest order sensor will most likely be a Pyramid sensor. We just investigate there the “mechanics” of the simulation.

The SCAO system runs at 500 Hz, the XAO system at 4kHz. The SCAO is controlled with an MVM type MAP reconstructor, and the XAO is run using Frim3D, to speed up the simulations. All WFSs run in diffractive mode. In our simulation scheme, the frame rate of the XAO has to be an integer multiplier of the SCAO frame-rate – here the XAO runs 8x faster, which simplifies considerably the simulation of the temporal aspects. Note that the slow commands appear instantaneously every 8 high order command.

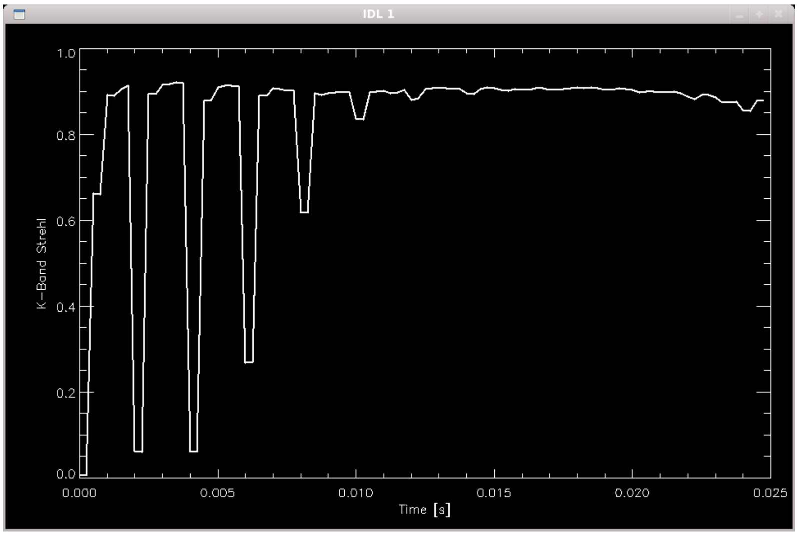

Figure 3: Strehl ratio (K-band) as a function of time, for the cascaded AO system.

The result is seen in the figure above. The Strehl starts low, as both system's DMs are flat. Then, the Strehl increases, thanks to the fast XAO system. After 8 iterations of the XAO, the slower SCAO system makes its first actuation. The total Strehl goes down, because now the XAO corrects the full atmosphere (it sees Atmosphere – M4 + its own shape which was almost the atmosphere as M4 was flat in the previous iteration)! But, since it is fast, it catches up therefore the Strehl goes up again.
This behaviour continues for a few loop cycles of the low order system, until it has caught up. At the end, the system reaches a stable regime, where the slow system corrects the low order modes, and the XAO corrects the remaining turbulence – high orders, not seen by the SCAO.
Of course, in a real system:

- One would first switch on the SCAO, and let it converge
- Then switch on the XAO. Otherwise, like here, the stroke needed by the XAO would be twice that of the full turbulence, whereas we want to reduce the required stroke.
- We ran these two simulations completely independently in Octopus. In a first step, the SCAO simulation was run, and the residual phase screens were saved to the disk. Then, the XAO was run, using as an input these residual screens.
- This is very efficient computationally since one doesn't need to run two simulations simultaneously. Of course, it is also a bit clumsy, since the SCAO system would need to be re-run when modifications are made to it. Also, a lot of disk space is wasted by phase screens. However, we have demonstrated that such an implementation scheme works.
- In future simulations, we will replace the XAO SH with a Pyramid sensor, and start tackling the PCS instrument performance simulations.
- In addition to providing such an entertaining curve, the shapes of the XAO DM found in these simulations was used to investigate the properties required from the XAO deformable mirror (like inter-actuator stroke, and total stroke), see Stroebele et al [1].

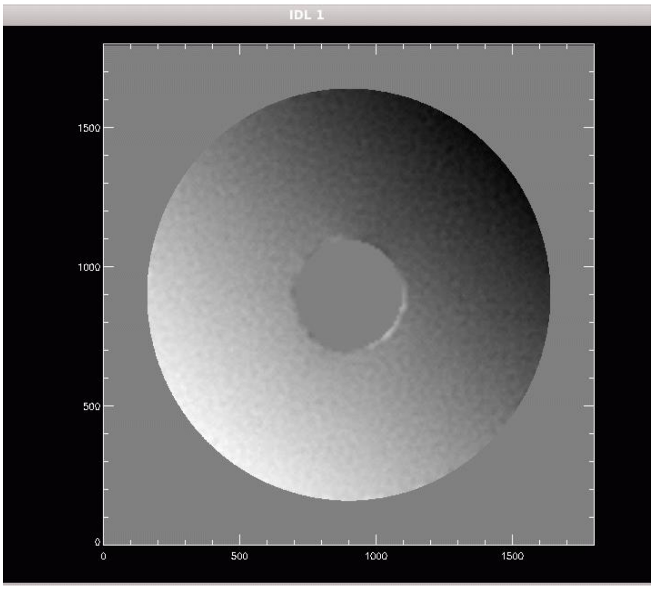

Figure 4: Residual phase after double stage AO correction.

4. METIS SCAO PYRAMID WITH 0 MODULATION

In this section, we look a “backup option” for an infrared sensing Pyramid sensor (sensing wavelength 2.2um), without any modulation. Usually, a Pyramid sensor used as a WFS requires some amount of modulation to work in a stable and linear regime.

In our case here (with the mid-IR METIS instrument), the modulation has to be done in a cold environment. We explored whether one could simply drop the modulation (probably not!) or live with a broken modulator in a degraded mode (perhaps…). To this end, we simulated a zero modulation Pyramid. The Strehl vs time can be seen below (on top, SE Strehl, bottom LE).

We can see that significant correction is obtained even without modulation. This is encouraging. Of course, there is a non-negligible performance loss, as with a more conventional modulation, we reach a Strehl of ~75%-80%. However, for some mid-IR science cases, perhaps the achieved Strehl is still sufficient?

Some stability issues are present (the short exposure Strehl seems to be going down on longer time scales), so modulation 0 is not very stable, and will need some more work should it be considered, even as a backup option. However, the situation doesn’t look completely desperate.

Note that in our simplified case, we did not use a thick spider – which may degrade performance.

A possible way to improve would be to use the method proposed by Korkiakoski et al [2], which has been shown to significantly stabilize and improve the performance of a non-modulated Pyramid sensor, by boosting the gain of saturated modes. This avenue remains to be explored.

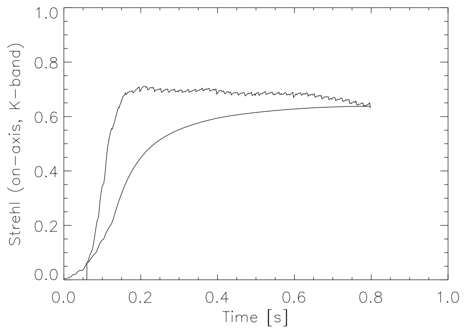

Figure 5: Strehl as a function of time, for a PYR WFS correction with 0 pyramid modulation.

5. LTAO / MCAO

We have run many simulations to compare two AO systems based largely on the same components (6 LGSs, the ELT's M4 adaptive mirror) but differing in their post-focal implementation. The MCAO has two post-focal DMs, and 3 NGS sensing arms patrolling a 2' field (diameter). The LTAO system has only one NGS, patrolling a 2' FOV (diameter).

Currently these simulations focus on the sky coverage improvement brought by the sharpening of the NGS by the post-focal MCAO DMs, vs no sharpening by the LTAO system. Of course, this could be remedied by adding DMs into the NGS path of the LTAO, but at a cost. Below we show the PSFs, in the NGS sensing path, at 1.6um, for MCAO (at 60'', on the left) and LTAO (at 30'' and 60'', middle and right, respectively) off-axis. It is clear that in this case, the MCAO brings a significant gain in PSF sharpness, i.e. a positive impact on sky coverage.

Another direction of the simulations is the inclusion of the telescope error sources into the end-to-end tool, and the optimization of the NGS sensors for a low flux case (with wind shake).

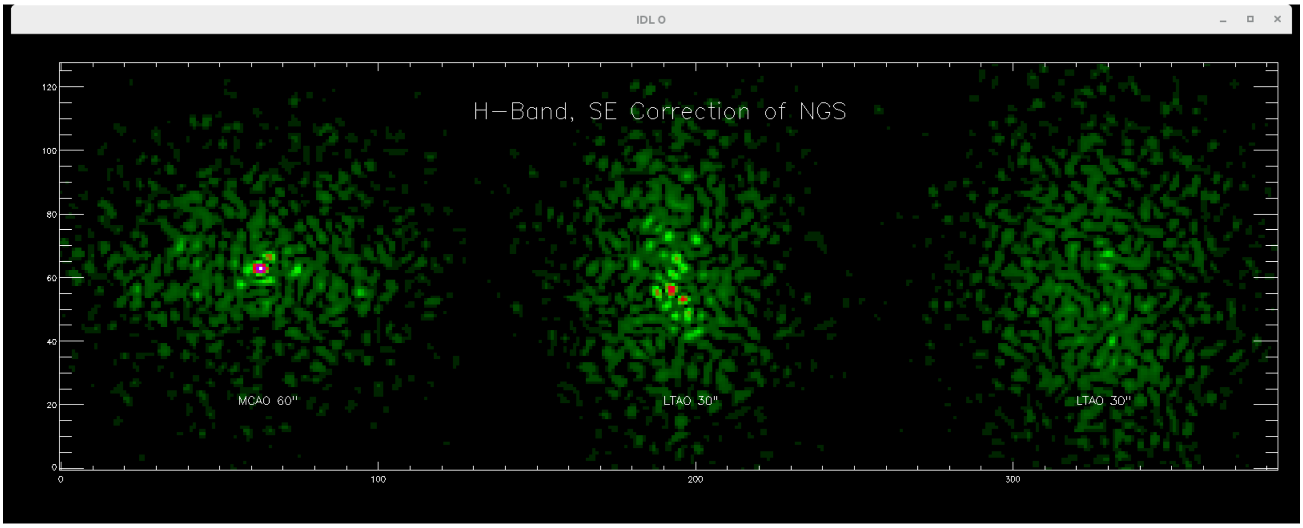

Figure 6: Effect of correcting the TT star with AO: on the left, with MCAO (some degree of correction is observed off-axis), LTAO (30'' from the axis) and LTAO at 60'' off-axis, where correction by the AO (due to central optimization) is small.

6. OCTOPUS AROUND THE WORLD!

Octopus spreads its tentacles! We have now installed the code in Linz, on the Cluster of the Austrian Academy of Sciences – Radon. As a result, some papers presented at this conference have emerged:

- Shatokhina et al, two novel algorithms for wavefront reconstruction from pyramid sensor data: Convolution with Linearized Inverse Filter and Pyramid Fourier Transform Reconstructor
- Raffetseder, LTAO on ELTs with Spiders
- Hutterer et al, Wavefront Reconstruction from Pyramid Sensor Measurements based on the Inversion of the Finite Hilbert Transform
- Saxenhuber et al, Comparison of layer compression methods and joint
- Obereder, On the performance of reconstruction methods in the presence of spiders
- Wagner et al., PSF reconstruction and deconvolution for extremely large telescopes

Also, Octopus has been used at the University of Canterbury in New Zealand, to investigate different types of the Pyramid sensor:

- Clare et al., Numerical Evaluation of Pyramid Type Sensors for Extreme Adaptive Optics for the European Extremely Large Telescope

This shows that there is now a small community developing and using the Octopus simulation tool.

REFERENCES

[1] Stroebele et al, “The ESO DM development programme”, these proceedings.
[2] Korkiakoski et al, Appl Opt, (2008)