ULTIMATE AO simulations

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Outline

- Introduction & background
- Simulation results
- Next steps
- Conclusions
System diagram

Ultimate-GLAO (Ultimate-LTAO)

Telescope

ASM

LGSF

Laser head  Laser head

LLTs  LLTs

BTOs  BTOs

UGCS

WAF (Cass or Nasmyth)

Structure

NGS WFS

LGS WFS

RTS

GSL

GSL
WFS adaptor flange

- Science FOV baseline 14’, but can be smaller
- LGS patrol area in the circle surrounding the science field
WFS adaptor flange

- Pick one GS in each crescent
- Margin of ~2” required
Referentials

- We use instrument coordinates in our simulations.
- 1-4 NGS: positions do not depend on clocking, pupil rotation and vignetting change.
- 4 LGS: positions change depending on clocking, pupil rotation and vignetting constant.
- Science field evaluated over a grid of 7x7 PSFs.

Default: 22.5 deg
Simulations in 3 stages

1. System design optimisation
   • parameters (number of subapertures, WFS pixel size, AO system update rate, controller loop gain) are optimised

2. Final system design performance
   • system performance evaluated using the optimised parameters

3. Full statistical performance prediction
   • Based on a set of actual targets, statistical distribution of the Sodium returns, turbulence profiles, many performance points are evaluated
## Simulation parameters: fixed

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Parameter</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope</td>
<td>Outer diameter</td>
<td>7.92m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inner diameter</td>
<td>0.277m</td>
<td>Cent. cone (350mm) being discussed</td>
</tr>
<tr>
<td></td>
<td>Pupil map</td>
<td>0.448</td>
<td>To be generated to a fits image</td>
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<tr>
<td>ASM</td>
<td>Outer diameter</td>
<td>1.265m</td>
<td>Need the drawings</td>
</tr>
<tr>
<td></td>
<td>Number of actuators</td>
<td>924</td>
<td>Not to be optimised</td>
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<tr>
<td></td>
<td>conjugation altitude</td>
<td>-80m</td>
<td></td>
</tr>
<tr>
<td>LLT</td>
<td>Location</td>
<td>Side Launch</td>
<td>Picked from configs in Mitsubishi analysis</td>
</tr>
<tr>
<td></td>
<td>Diameter</td>
<td>45cm</td>
<td>Assuming filled aperture</td>
</tr>
<tr>
<td></td>
<td>Laser $1/e^2 \odot$</td>
<td>30cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tube seeing</td>
<td>1&quot;</td>
<td>In addition to atmospheric seeing</td>
</tr>
<tr>
<td></td>
<td>Optical throughput</td>
<td>70%</td>
<td>Includes Beam Transfer Optics + LLT</td>
</tr>
<tr>
<td>LGS</td>
<td>Number of LGS</td>
<td>4</td>
<td>On a square geometry</td>
</tr>
<tr>
<td></td>
<td>LGS asterism radius</td>
<td>Sci. FoV $\times \sqrt{2}/2$</td>
<td>$R_{ast}$ in figure 1</td>
</tr>
<tr>
<td></td>
<td>LGS asterism clocking</td>
<td>22.5°</td>
<td>$\theta_{ast}$ in figure 1</td>
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<tr>
<td>Laser</td>
<td>Type</td>
<td>TOPTICA 20W</td>
<td>+ 10% modulation in side band</td>
</tr>
<tr>
<td></td>
<td>Na return at zenith</td>
<td>See section 4.3</td>
<td></td>
</tr>
<tr>
<td>LGS WFS</td>
<td>Optical Throughput</td>
<td>0.448</td>
<td></td>
</tr>
<tr>
<td>NGS WFS</td>
<td>Effective $\lambda$ visible</td>
<td>650nm</td>
<td>For visible detectors</td>
</tr>
<tr>
<td></td>
<td>Effective $\lambda$ NIR</td>
<td>1.64(\mu)m (H)</td>
<td>For NIR detectors</td>
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<tr>
<td></td>
<td>Optical Throughput</td>
<td>0.448</td>
<td>Define for visible and NIR</td>
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<tr>
<td></td>
<td># of TT+Focus</td>
<td>one or all</td>
<td>Compared to TT only</td>
</tr>
<tr>
<td>Operation</td>
<td>Zenith angle</td>
<td>30°</td>
<td>Default, see 4</td>
</tr>
<tr>
<td>Imager</td>
<td>Wavelength</td>
<td>Ks (2.15(\mu)m)</td>
<td>Major science cases</td>
</tr>
</tbody>
</table>
Simulation parameters: turbulence

- $C_n^2$ profiles in (Oya, 2014), except low altitudes from (Chun, 2009)

<table>
<thead>
<tr>
<th>Alt [m]</th>
<th>$C_n^2$ 25% [m$^{1/3}$]</th>
<th>$C_n^2$ 50% [m$^{1/3}$]</th>
<th>$C_n^2$ 75% [m$^{1/3}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.766E-13</td>
<td>2.924E-13</td>
<td>4.031E-13</td>
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<tr>
<td>15</td>
<td>5.798E-14</td>
<td>5.007E-14</td>
<td>8.773E-14</td>
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<tr>
<td>30</td>
<td>2.155E-14</td>
<td>1.754E-14</td>
<td>1.537E-14</td>
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<tr>
<td>60</td>
<td>7.311E-15</td>
<td>1.279E-14</td>
<td>1.853E-14</td>
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<tr>
<td>119</td>
<td>2.626E-15</td>
<td>6.281E-15</td>
<td>2.050E-14</td>
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<tr>
<td>353</td>
<td>2.171E-14</td>
<td>4.132E-14</td>
<td>7.964E-14</td>
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<tr>
<td>1500</td>
<td>9.804E-15</td>
<td>2.348E-14</td>
<td>6.452E-14</td>
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<tr>
<td>9333</td>
<td>6.022E-14</td>
<td>8.385E-14</td>
<td>1.242E-13</td>
</tr>
<tr>
<td>Total</td>
<td>3.578E-13</td>
<td>5.277E-13</td>
<td>8.136E-13</td>
</tr>
<tr>
<td>$r_0$ (500cm) [cm]</td>
<td>14.9</td>
<td>11.8</td>
<td>9.1</td>
</tr>
</tbody>
</table>
Parameters to scan in phase 1

• Seeing cases 25, 50 and 75
• FOV: 14’
• Number of WFS subapertures: 26, 32
• LGS WFS pixel size: 0.1”—0.8”
• LGS WFS FOV: at least 5”
• LGS WFS framerate: 100–600 Hz, limited by ORCA Flash
Simulation implementation

- Use Google Cloud Compute Engine to run YAO simulations
- Low-cost & convenient platform
  - $0.01 for one CPU hour + storage etc. (preemptible, i.e. may be rebooted)
  - Stage 1 simulations of ~23,000 h: AU$800
Performance as a function of FOV

- Preliminary results for FWHM dependency on the corrected FOV
- Reduce baseline FOV of 14’ to 10’:
  - Gain 10-20 mas 4% in FWHM
- Reduce baseline FOV of 14’ to 6’:
  - Gain 50-80 mas (17%) in FWHM
- Even more significant gains at smaller fields
Optimal LGS WFS pixel size

- Optimise loop gain & system framerate
- FWHM as a function of LGS flux & pixel size
- **Optimal LGS pixel size 0.6”**
- LGS flux can be 25% of expected, before performance reduction
Comparison to earlier simulations

Compare the case with 30 deg zenith angle

Ratios of noise-equivalent-area (NEA)

- Differences between Oya’s and ours:
  - Oya’s coarse turbulence sampling at altitudes of 0—100 m
  - Oya’s FOV of 10’ vs. 14’ in our simulations

<table>
<thead>
<tr>
<th>Seeing case</th>
<th>Oya NEA ratio</th>
<th>YAO Seeing FWHM</th>
<th>YAO GLAO FWHM</th>
<th>YAO Est. NEA ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.3</td>
<td>0.47”</td>
<td>0.23”</td>
<td>0.3</td>
</tr>
<tr>
<td>50</td>
<td>0.35</td>
<td>0.60”</td>
<td>0.32”</td>
<td>0.4</td>
</tr>
<tr>
<td>75</td>
<td>0.5</td>
<td>0.82”</td>
<td>0.51”</td>
<td>0.4</td>
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(Oya, 2014)
K-band
Comparison to earlier simulations

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Clear message:
• GLAO reduces FWHM by 50%
• Median seeing GLAO performance: 0.2-0.3”

Ratios of noise-equivalent-area (NEA)

(Oya, 2014)

K-band

zenith angle [deg]
Next steps

• Discrepancies between YAO & Oya’s simulations
  • Clarify turbulence normalisation
• Finish simulation stages 1—2
  • Optimise of NGS WFS pixel size
  • Decide between visible and infrared detector for NGS WFS (based on expected NGS constellations)
• Complete stage 3 of simulations
  • Compile statistical performance estimates using realistic pointings, turbulence profiles and sodium returns
Simulation stage 3: future results

- For final performance estimate, we create 1000 samples using realistic settings

- We obtain:
  - For each sample: performance, e.g., FWHM, for seeing limited & GLAO corrected image
  - Histograms showing the likelihoods for seeing cases and corrections
Conclusions

- Most of simulations for stages 1—2 completed (optimised design parameters)
- Good agreement with prior simulations, in particular regarding the ratio that GLAO correction will achieve: FWHM reduced by ~50% in all seeing conditions
- Minor discrepancies to sorted out: make sure our turbulence is not too conservatively scaled (to accurately predict expected absolute GLAO corrected FWHM)
- Minor tasks remain to complete stages 1—2:
  - NGS WFS pixel size & used wavelength
- Simulation stage 3, full fledged performance prediction, will commence shortly
Thank you for your attention!
PSF quality as a function of field position.
Seeing 50. 20000 iterations
Convergence: PSF quality

5000 iterations (1)  5000 iterations (2)  20000 iterations
Simulations: convergence

>20000 iterations for FWHM

>5000 iterations for EE50