Continuous-wave lidar method - line of sight sodium profiles during LGS-AO operation

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The overall scope of the work of this ongoing research is to see if the need of NGS focus sensing can be removed in LGS-AO.

The method yields line-of-sight LGS sodium density profiles. allows sodium density structure statistics while telescope is in operation

The sodium profiles could be used as input for matching filter algorithms.
Sodium layer variability

- sodium in the layer originates from ablation of meteorites
- layer shows temporal and spatial evolution
- layer density structure is affected by Kelvin-Helmholtz instabilities, gravity waves, sporadic sodium layers and meteor trails

figures:
Pfrommer et al. (2009)
Induced wavefront error

- sodium centroid changes induce focus wavefront error
- wavefront error is proportional to telescope diameter squared

\[ \sigma_{wfe} = \frac{1}{16\sqrt{3}} \frac{D^2}{h^2} \Delta h \]
- for the ELT 1 m of centroid change induces a wavefront error of 7 nm

figure & formula: Herriot et al. (2006)
CW lidar method

- partial-amplitude modulation of cw laser
- cross-correlating LGS return flux with random sequence used for modulation
- for partial amplitude modulation a device like an AOM could be used (MHz-scale)
CW lidar method

In AO system leakage light from mirrors or beam splitter (approx. 3 %) could be used
Analysis & simulations

- analytical calculation of centroid error for photon-noise limited case

\[ \sigma_z \approx \frac{\sqrt{2 - \epsilon}}{\epsilon} \sqrt{\frac{n}{6N_0}} Z \]

<table>
<thead>
<tr>
<th>parameter</th>
<th>description</th>
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<tbody>
<tr>
<td>( \epsilon )</td>
<td>modulation strength</td>
</tr>
<tr>
<td>( N_0 )</td>
<td>total number of photons at ( \epsilon = 0 )</td>
</tr>
<tr>
<td>( n )</td>
<td>number of samples</td>
</tr>
<tr>
<td>( Z )</td>
<td>altitude range of layer</td>
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Performance on ELTs

- simulations carried out for different profile shapes and integration times for ELTs
- analytically-predicted centroid error and simulations agree well

<table>
<thead>
<tr>
<th>input parameter</th>
<th>value</th>
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<tbody>
<tr>
<td>LGS magnitude</td>
<td>7.0</td>
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<tr>
<td>flux at primary mirror</td>
<td>15.8 Mph/m²/s</td>
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<tr>
<td>telescope throughput</td>
<td>0.3</td>
</tr>
<tr>
<td>fraction of leakage light</td>
<td>0.03</td>
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results shown in figure for ELT
Performance on ELTs

Wavefront sensing in the VLT/ELT era, 4th edition, Firenze 28th-30th Oct 2019
Conclusions

- retrieving profiles inducing wavefront errors < 50 nm on timescales of some seconds is possible for ELTs
- different scenarios (< 50 nm): 1 LGS, 0.6 modulation → 30% less LGS flux
  6 LGS, 0.3 modulation → 15% less LGS flux
- future scenario (< 20 nm): 6 LGS, 2.5 x return flux, 2 seconds integration, 0.6 modulation → 30% less LGS flux
- profiles could be used as input for matched-filter algorithms, quantitative study of performance needed
- retrieving profiles of high accuracy on sub-second timescales seems difficult, is sub-second timescale needed? more work is ongoing
Thank you for your attention!