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

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

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Scope

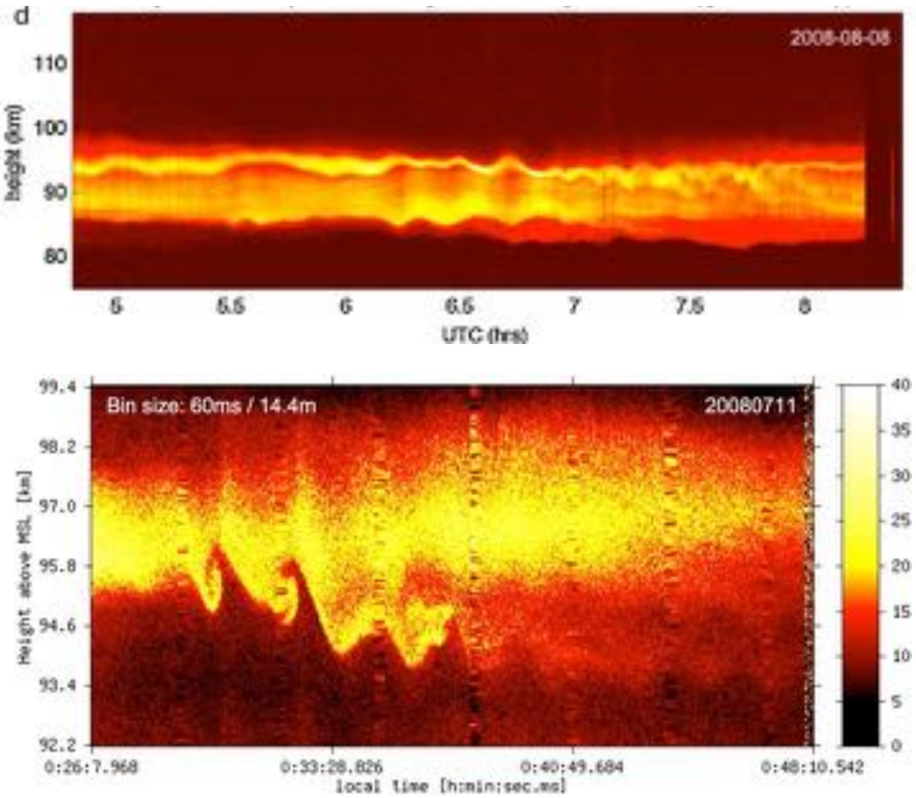
The overall scope of the work of this ongoing research is to see if the need of NGS focus sensing can be removed in LGS-AO.

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.

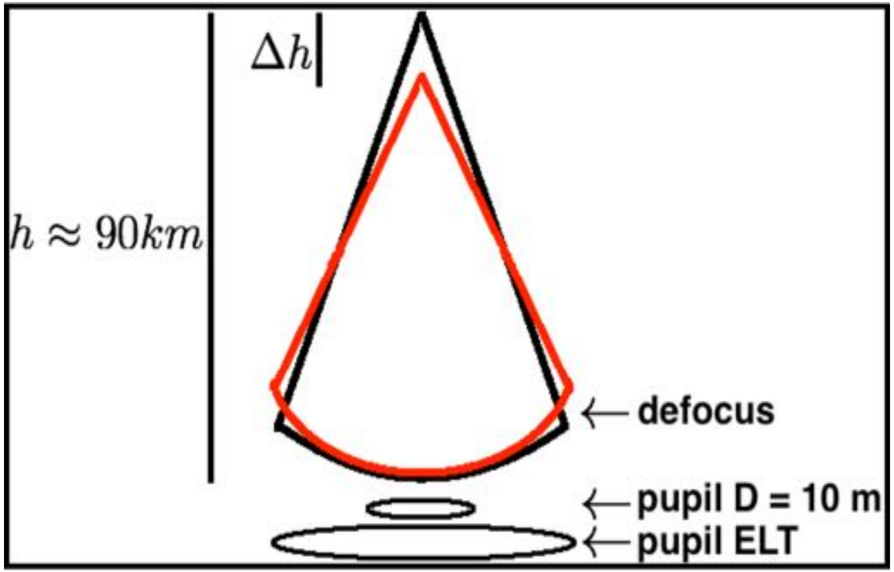
Sodium layer variability



- **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 squarred**

$$\sigma_{wfe} = \frac{1}{16\sqrt{3}} \frac{D^2}{h^2} \Delta h$$

- **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)

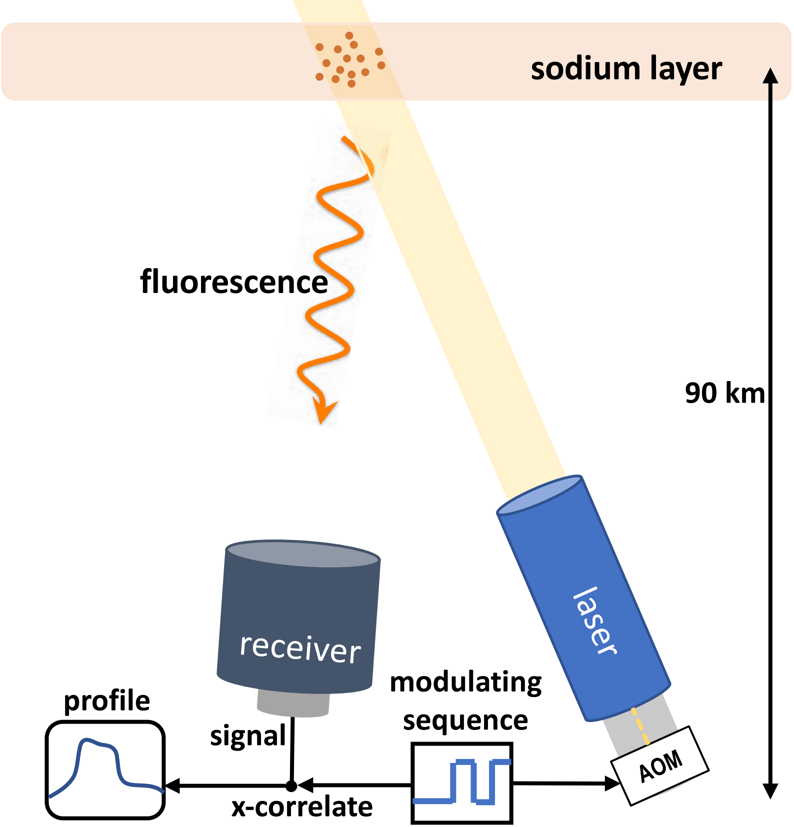
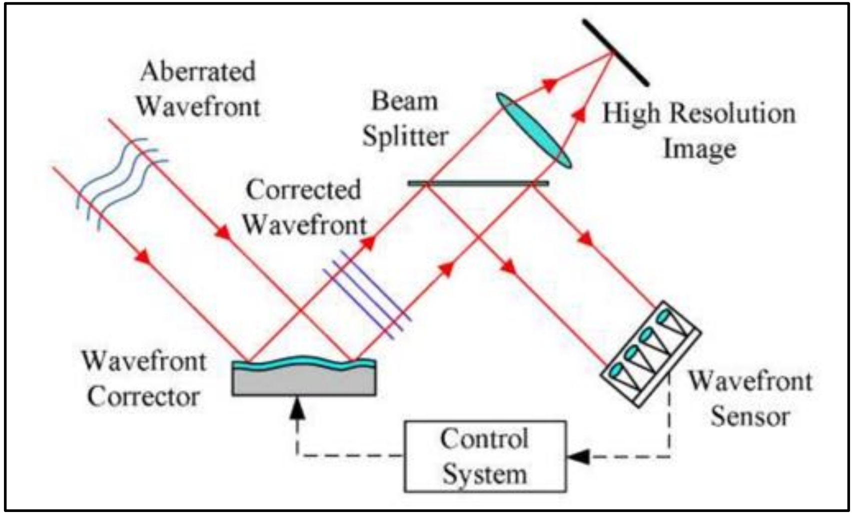
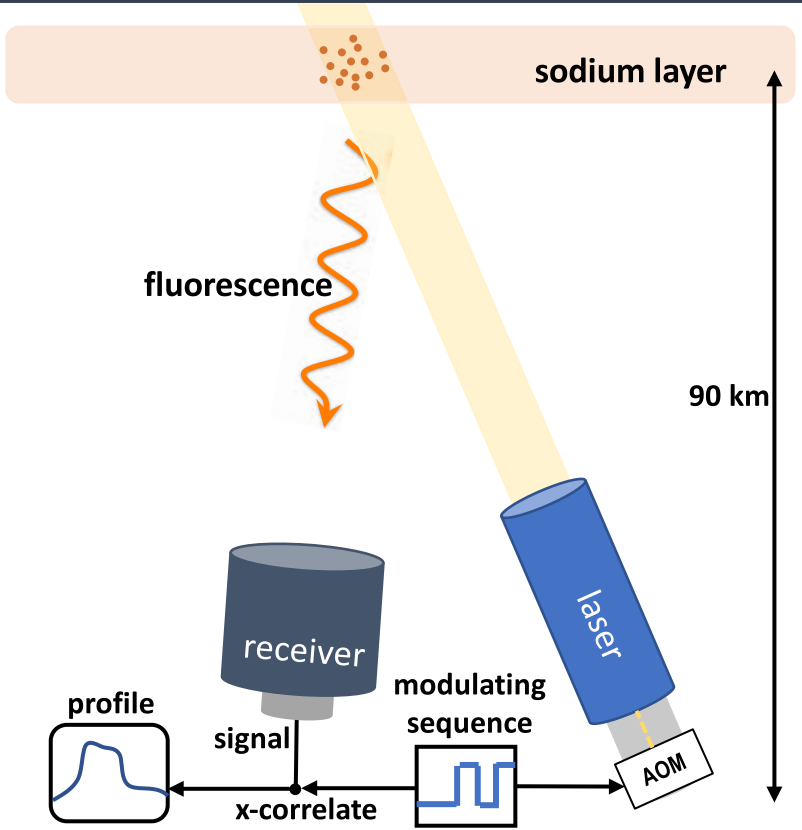


figure: adapted from Bustos et al. (2018)

CW lidar method



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



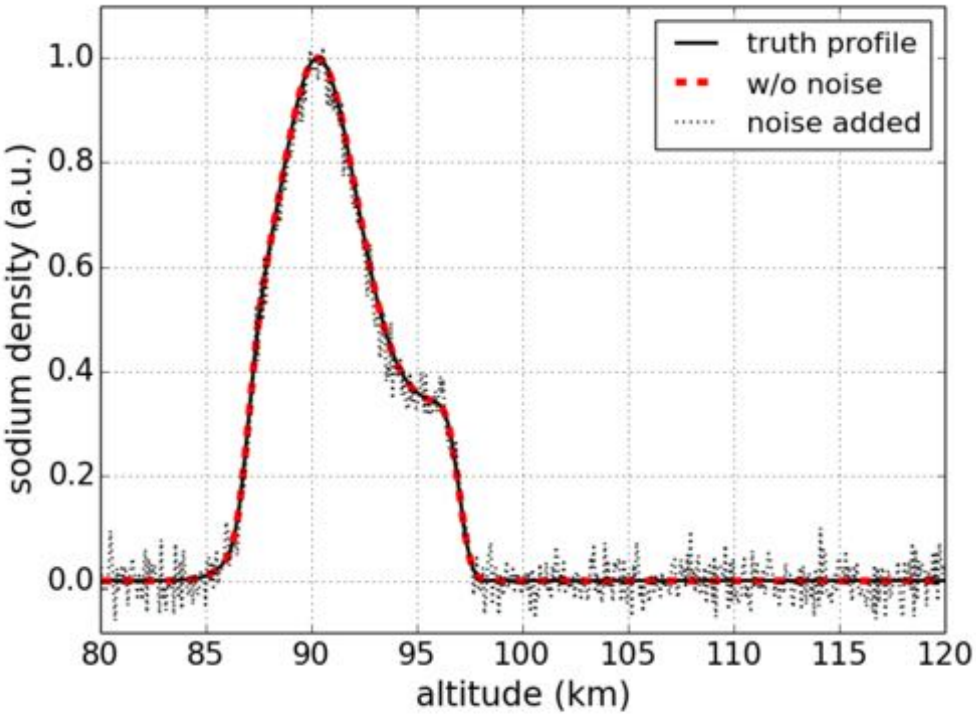
figures: Iqbal et al. (2009)
Bustos et al. (2018) [adapt.]

Analysis & simulations

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

$$\sigma_z \simeq \frac{\sqrt{2-\epsilon}}{\epsilon}\sqrt{\frac{n}{6N_0}}Z$$

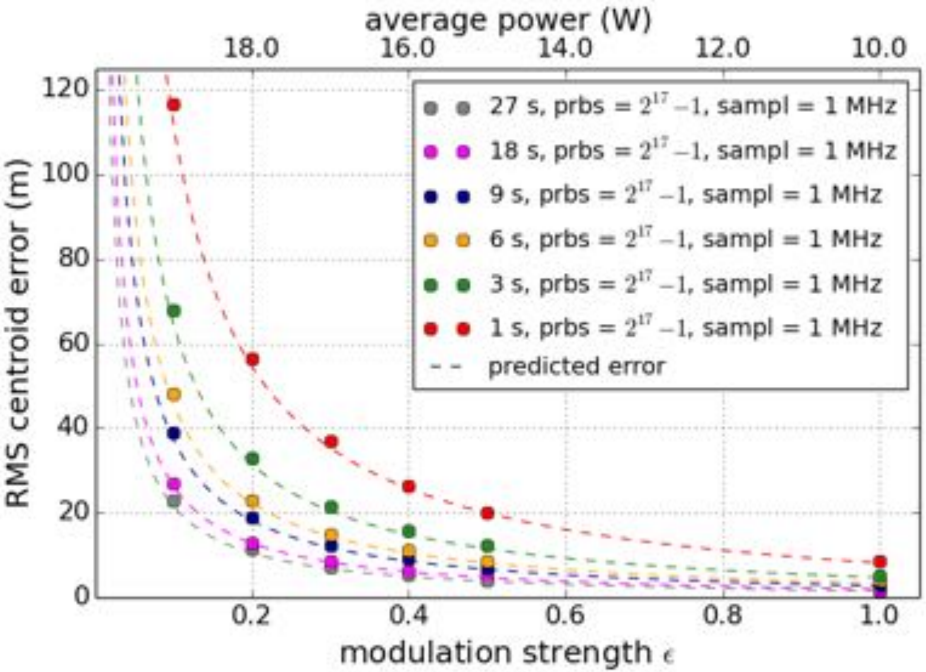
parameter	description
ϵ	modulation strength
N_0	total number of photons at $\epsilon = 0$
n	number of samples
Z	altitude range of layer



Performance on ELTs

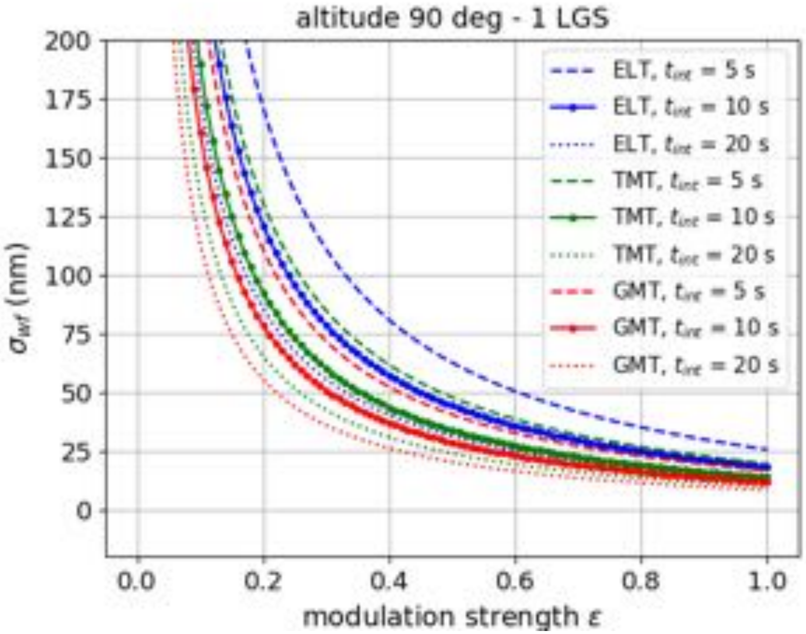
- **simulations carried out for different profile shapes and integration times for ELTs**
- **analytically-predicted centroid error and simulations agree well**

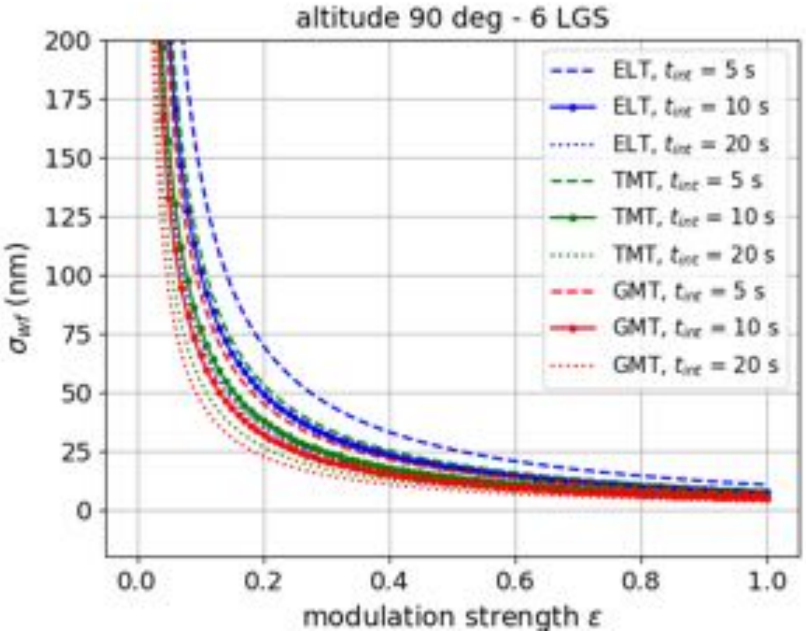
input parameter	value
LGS magnitude	7.0
flux at primary mirror	15.8 Mph/m^2/s
telescope throughput	0.3
fraction of leakage light	0.03

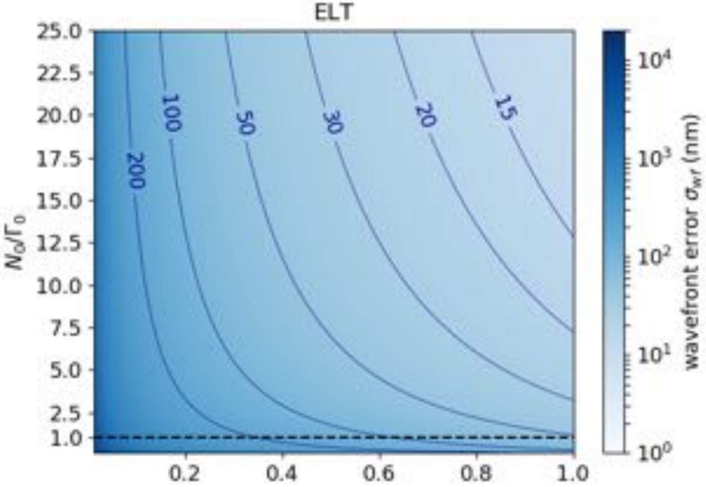


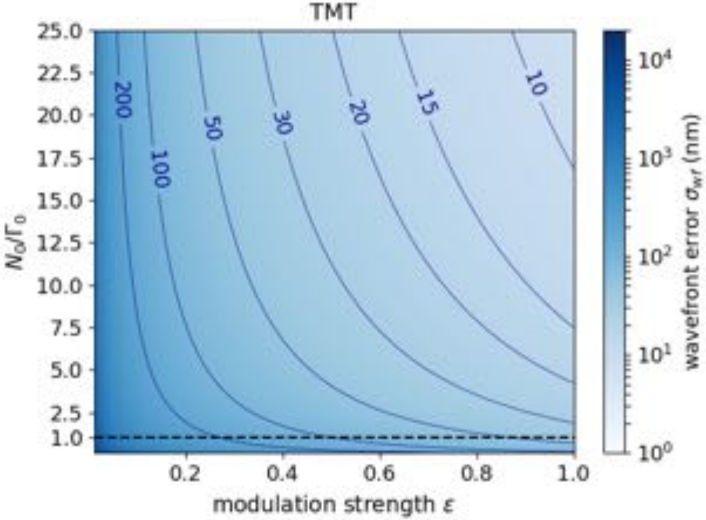
results shown in figure for ELT

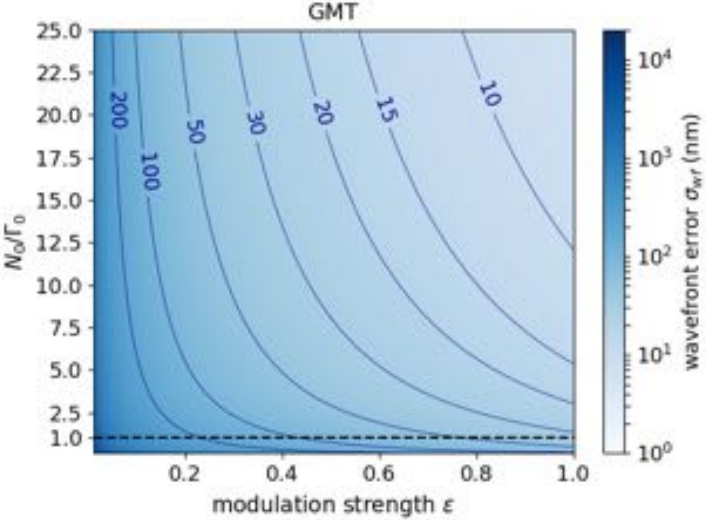
Performance on ELTs











parameter for Γ_0	value
integration time	1 s
flux at primary mirror	15.8 $\mathrm{Mph/m^2/s}$
telescope throughput	0.3
fraction of leakage light	0.03
used LGS	1

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!

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