Multiple Object AO with the AOF

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VLT ADAPTIVE OPTICS COMMUNITY DAY

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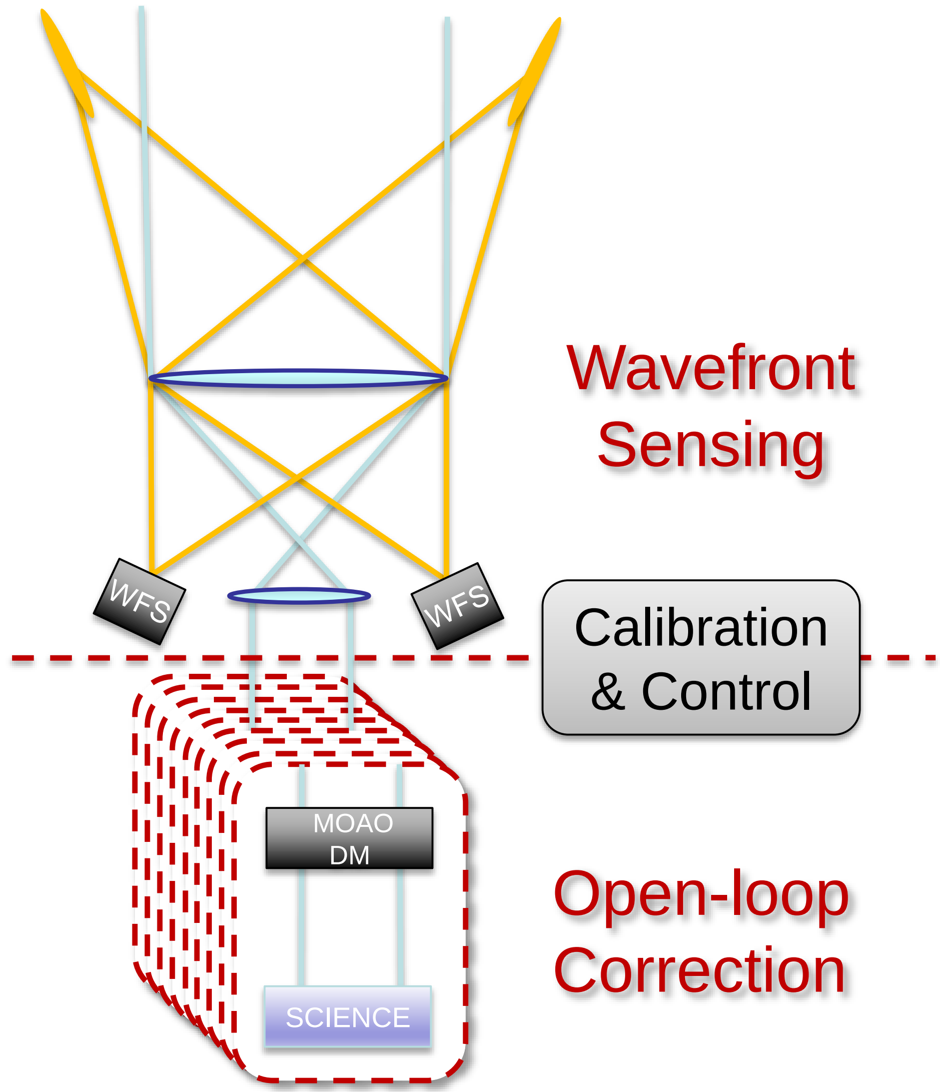
Talk outline

- MOAO tomography with the AOF
- MOAO correction and control
- MOAO on-sky performance
- VLT with AOF implementation
- Simulation results

Multiple Object AO

Conventional description:

MOAO uses several off-axis guide stars to correct along multiple lines of sight within a wide field of view where each line of sight is corrected by a deformable mirror operating in open-loop



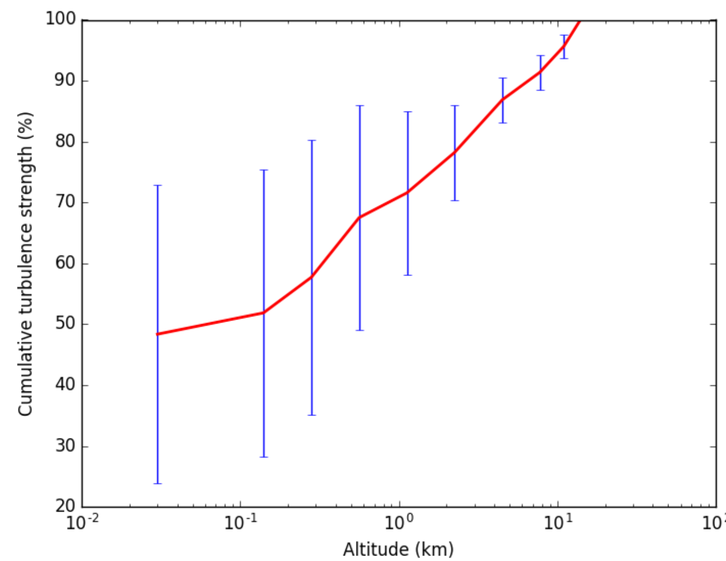
Turbulence profiles at the VLT

- AOF turbulence profiles are ground-layer dominated
  - – Typically 75% in first 500m

DIMM seeing (") at 30deg off-zenith	0.44 <0.55	0.65 0.55 – 0.76			0.87 0.76 – 0.98			1.09 0.98 – 1.2			1.31 1.2 – 1.42			1.53 >1.42
Probability (%) **Total = 100%**	7	6	**12**	6	6.5	13	6.5	4.5	**9**	4.5	3	**6**	3	13
Contribution < 500m (%)	**76**	**58**	**76**	**89**	**49**	**69**	**87**	**29**	**60**	**80**	**21**	**53**	**75**	**53**
Layer height (m)	Fraction of Cn2 (%)													
1.16*30	70	53	70	83	41	59	77	16	45	65	0	26	46	26
1.16*140	1	1	1	1	1	2	2	2	4	5	3	8	10	8
1.16*281	3	2	3	3	4	4	4	5	7	7	6	11	12	11
1.16*562	5	5	5	5	8	6	5	12	9	7	23	16	15	16
1.16*1125	0	0	0	0	1	1	0	11	3	0	28	6	1	6
1.16*2250	2	7	2	0	13	5	1	21	6	1	14	10	1	10
1.16*4500	5	11	5	1	15	9	3	16	12	4	14	10	6	10
1.16*7750	4	6	4	2	5	4	2	6	5	4	5	6	4	6
1.16*11000	4	6	4	2	6	5	3	6	5	4	4	4	3	4
1.16*14000	6	9	6	3	6	5	3	5	4	3	3	3	2	3

90% in ground
12% of the time

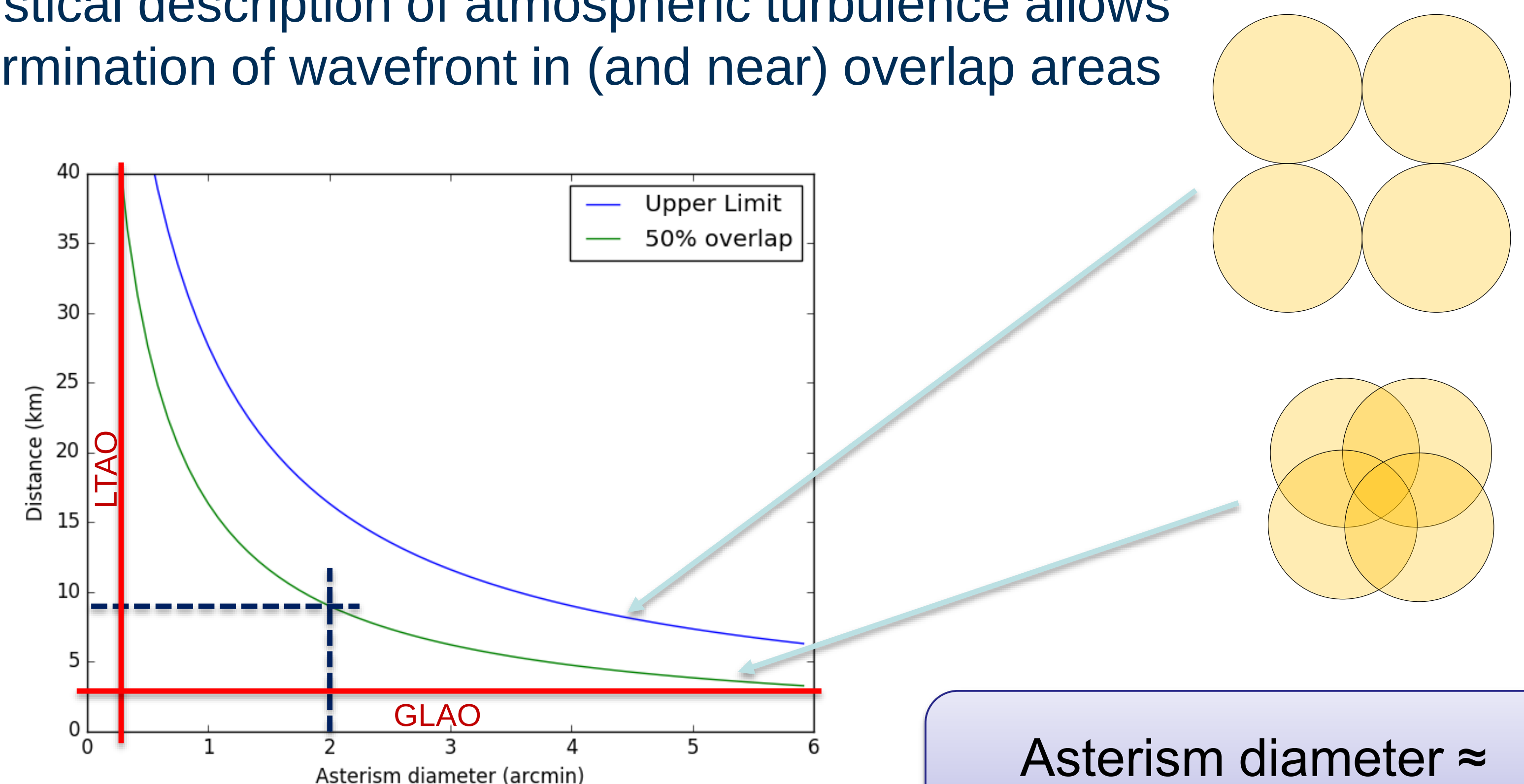
~25% in ground
7.5% of the time



Cumulative turbulence strength vs. altitude showing ±1σ strength variation

VLT Tomographic Volume

- Wavefront tomography relies on the overlap of pupils at altitude
- Statistical description of atmospheric turbulence allows determination of wavefront in (and near) overlap areas

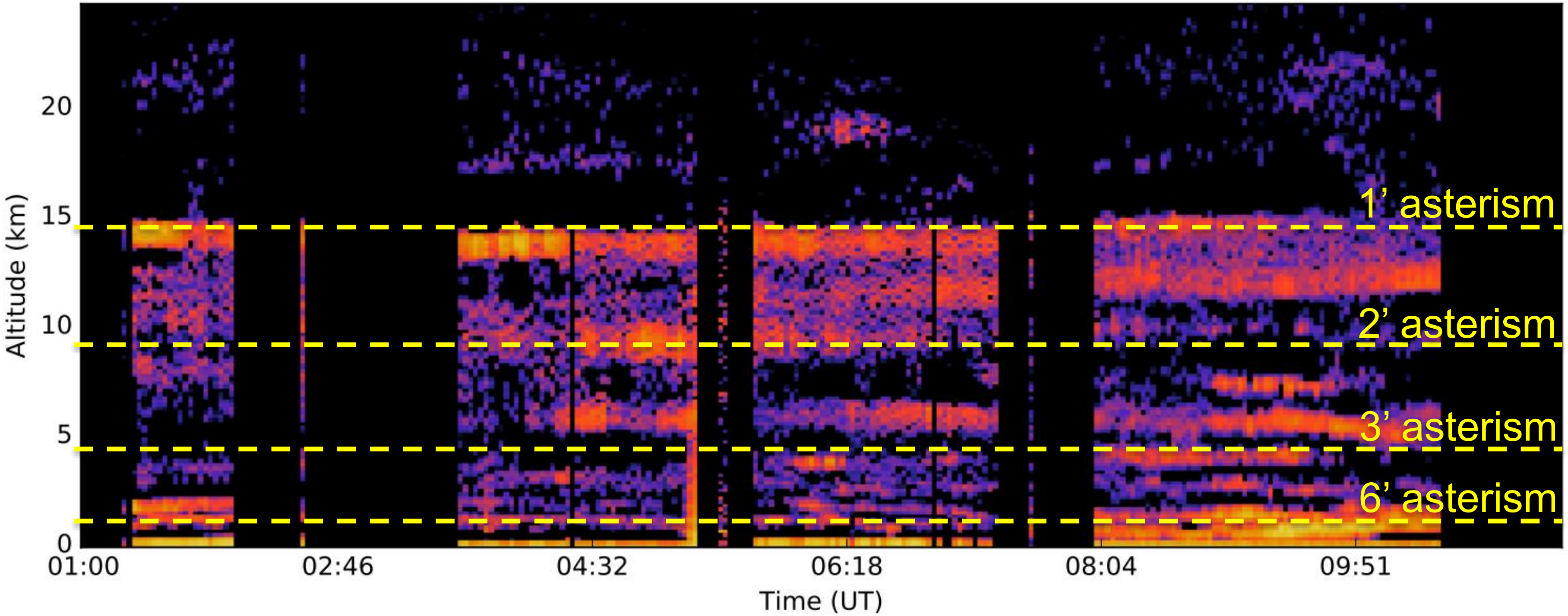


Overlap of the 4LGS meta-pupils at altitude for LGS asterisms of varying diameter

Asterism diameter ≈ Corrected field of view

MOAO Field of View

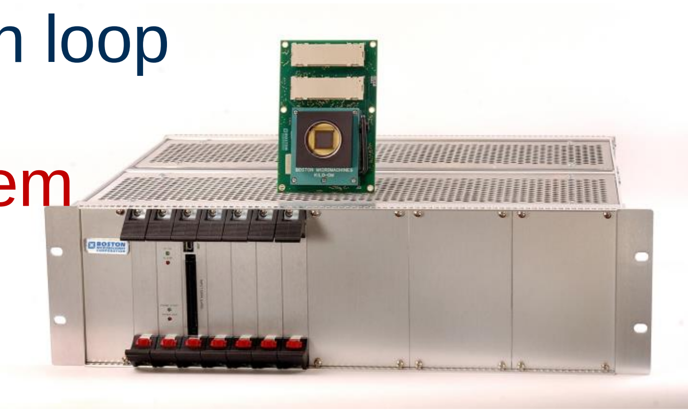
- Wide-field AO performance is determined by strength at altitude
  - AOF profiles do not have sufficient vertical resolution above 5km to determine if a 1,2 or 3' asterism would be optimal



Stereo-SCIDAR turbulence profile measured in Paranal from 22nd July 2016

Open-loop Correction

- Several deformable mirrors are capable of operating in open-loop with low error
- Open-loop capable means:
  - Actuator response is linear (or can be linearised)
  - Actuator response doesn’t vary with changes in temperature
  - Static offsets applied to the DM remain static under normal operation
  - Low hysteresis
- *Actual mirror shape = requested mirror shape*
- Several devices already exist with open loop errors <20nm RMS
- Open-loop correction is a solved problem



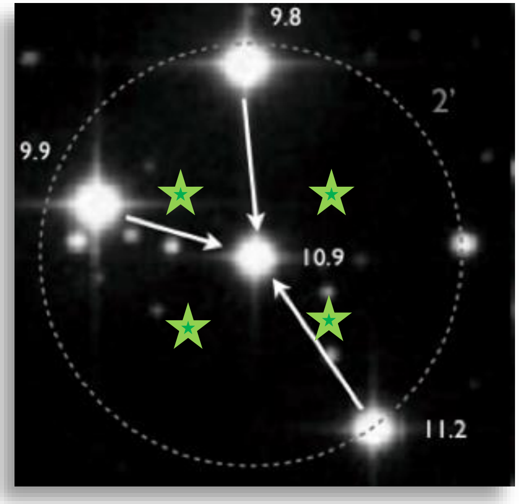
MOAO Control

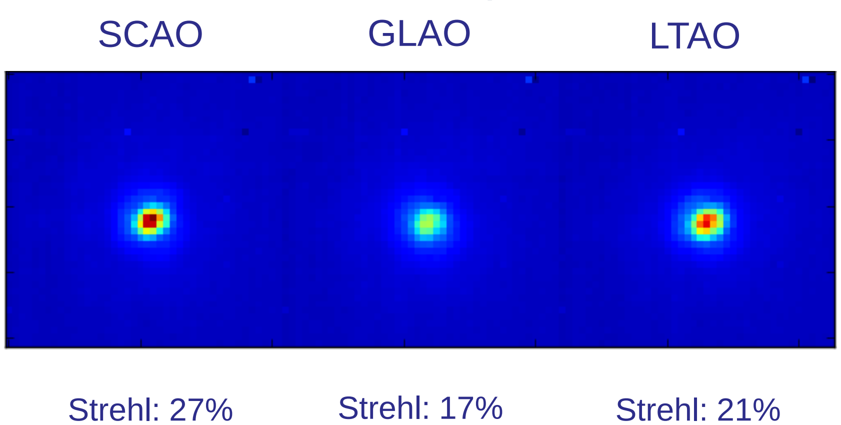
- MOAO control is very similar that used for LTAO systems
  - Adapted to multiple lines of sight rather than one
  - Control loop can/should be run at high gain
- WFS do not see correction therefore must remain linear over a wider range
- Tomography and control require a fixed alignment between pupils at DM and WFS
- Measurement of DM – WFS interaction matrices require additional functionality/components

MOAO on-sky performance

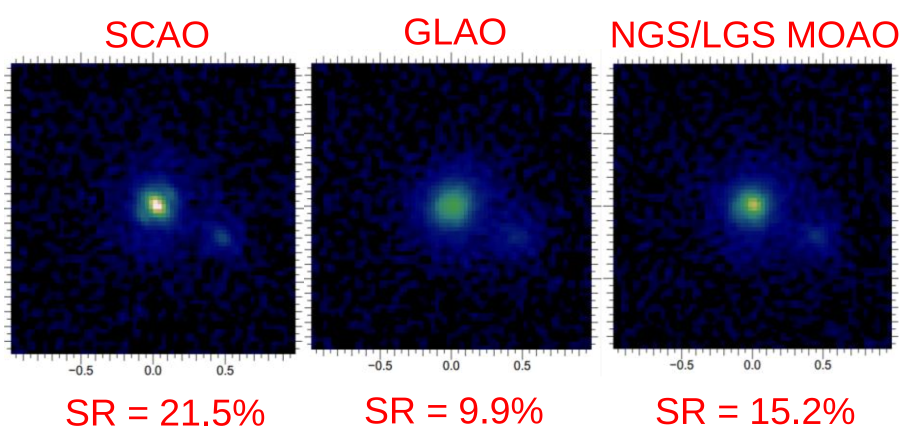
- MOAO performance and LTAO performance using the same LGS asterism are very similar
- CANARY tested closed-loop LTAO and open-loop LGS MOAO on-sky at the 4.2m WHT between 2013 and 2014
  - Only the location of the LGS WFS (before or after DM) was changed
- Differences in seeing conditions aside, results are comparable…

CANARY WFS configuration



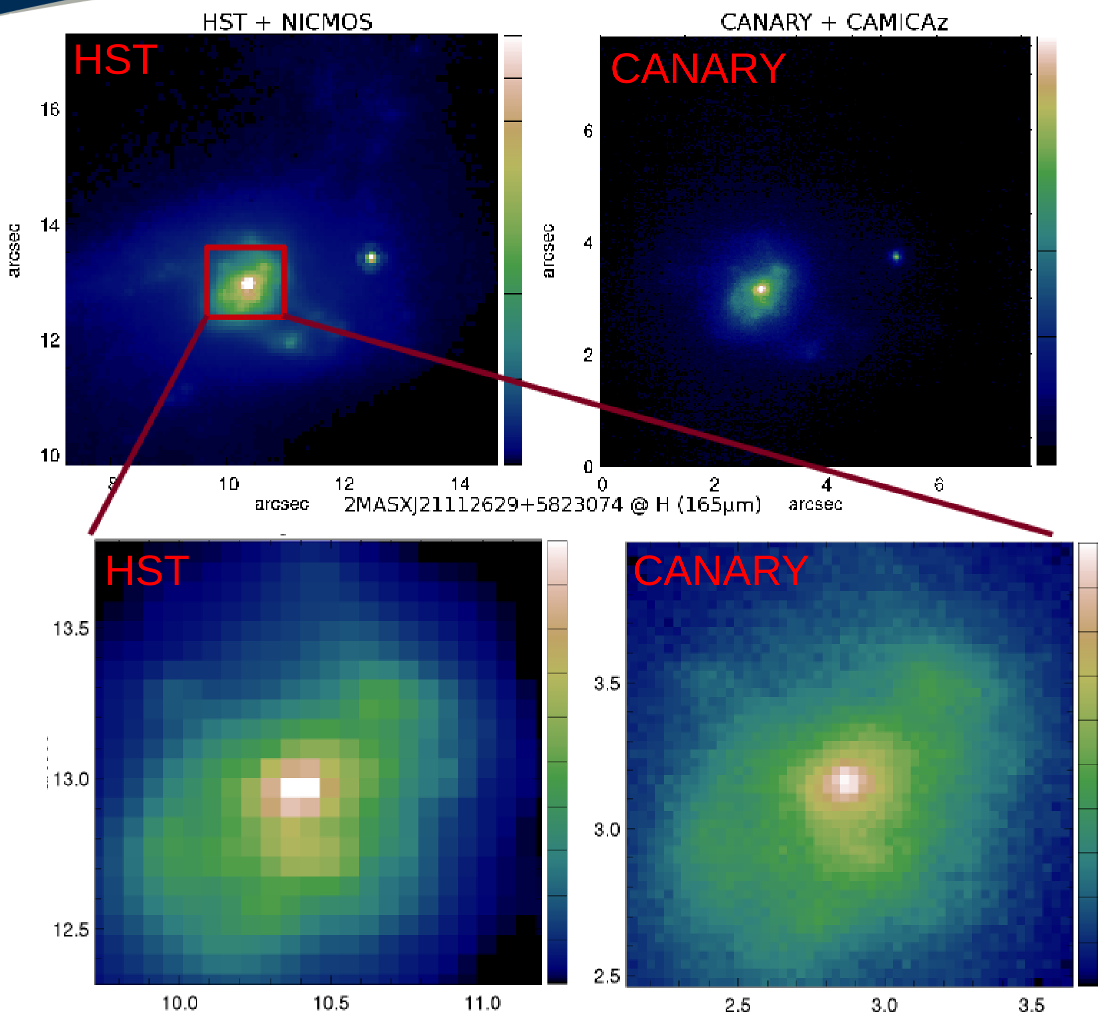


Low-order GLAO/LTAO 2013



Low-order GLAO/MOAO 2014

MOAO Science Demonstration



- Science observation demonstration
  - Total ~60 min exposure
- CANARY operating in open-loop tomographic mode
- LGS-only MOAO mode
  - 4 off-axis LGS and 1 off-axis TT star
- System stable throughout observation

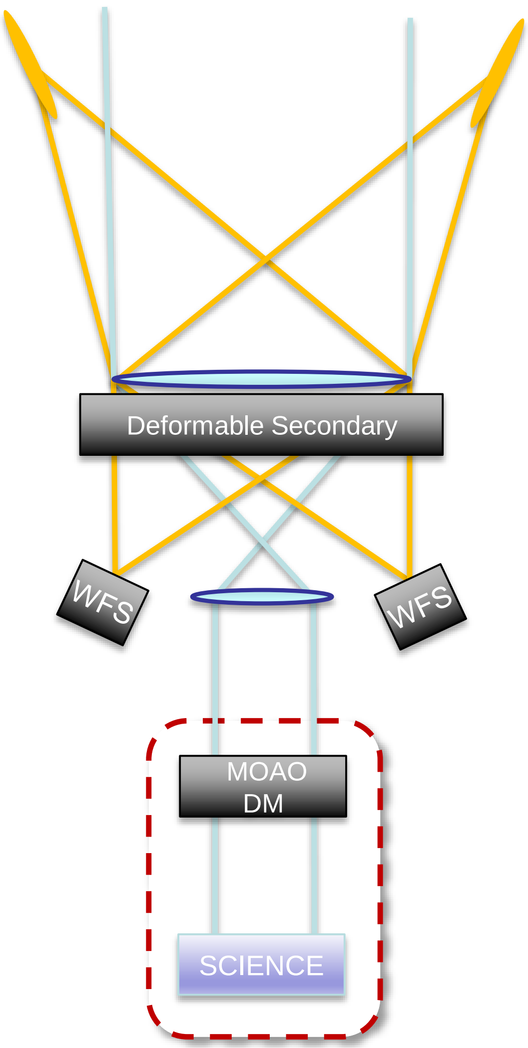
Gratadour *et al*, *“First demo science with MOAO: observations of distant merging galaxies with CANARY”*, SPIE 9148 (2014)

Multiple Object AO: Summary

- MOAO performance is highly dependent on LGS asterism diameter
  - Narrow asterism provides LTAO-like correction
  - Wide asterism provides GLAO-like correction
- LGS asterism diameter defines (approximately) the diameter of potential MOAO corrected field
  - AOF high altitude profiles too coarse to optimise for wide-field instruments
- Open-loop correction and control has been proven on-sky at both WHT with CANARY and Subaru with RAVEN

MOAO with the 4LGSF

- For wide-field MOAO, deformable secondary would be used to provide GLAO correction over whole field
- WFSs would observe partial correction from GLAO loop
  - Slightly reduce dynamic range requirements
- Need to remove effect of M2 correction to preserve wavefront statistics for tomography
  - Pseudo-open loop control not currently supported within SPARTA RTCS?
- With high-order GLAO, residual aberrations within MOAO channels, number of MOAO actuators could be significantly reduced



MOAO with the 4LGSF

- MOAO correction over the full field of the VLT not better than GLAO
  - Have to restrict LGS asterism diameter
- LGS can be augmented by bright, off-axis natural guide stars if field is large enough

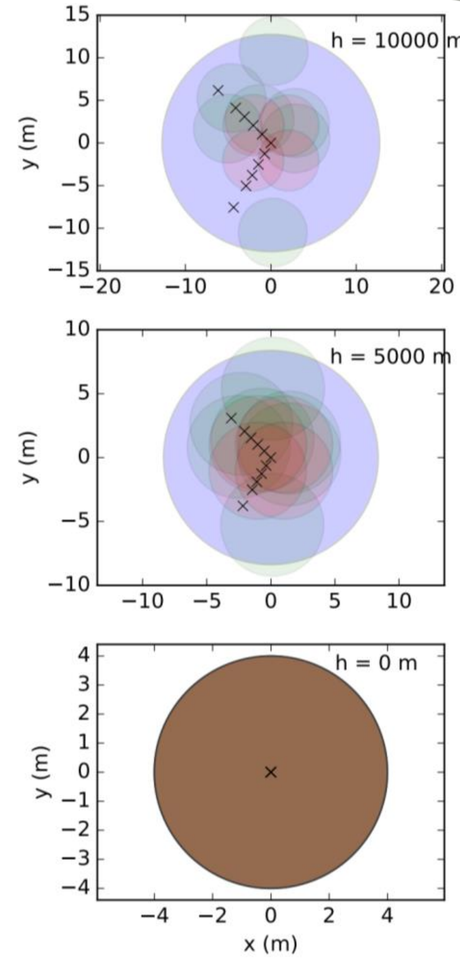
PROPOSAL

Provide GLAO correction using the DSM over a wide field from a restricted diameter LGS asterism

Populate the GLAO field with addressable spectrograph pickoffs

Include MOAO DMs within several pickoff channels to take advantage of the low tomographic error present in the central LGS field

KMOS + GLAO + MOAO



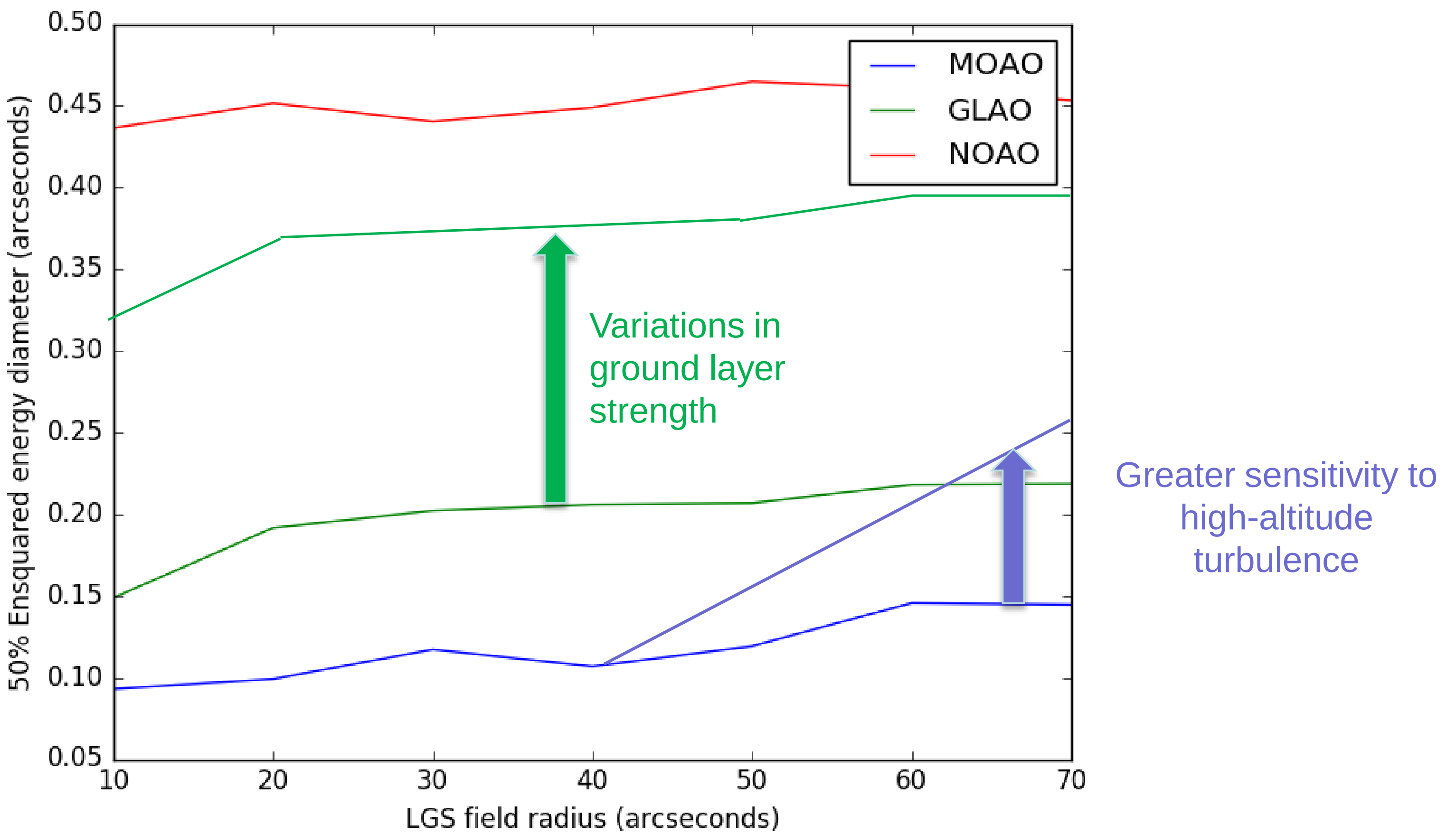
Pupil overlap at altitude for 2' diameter LGS (red), NGS < 16 (green) and 7.2' diameter science field (blue) for a GOODS-N field

GLAO/MOAO performance

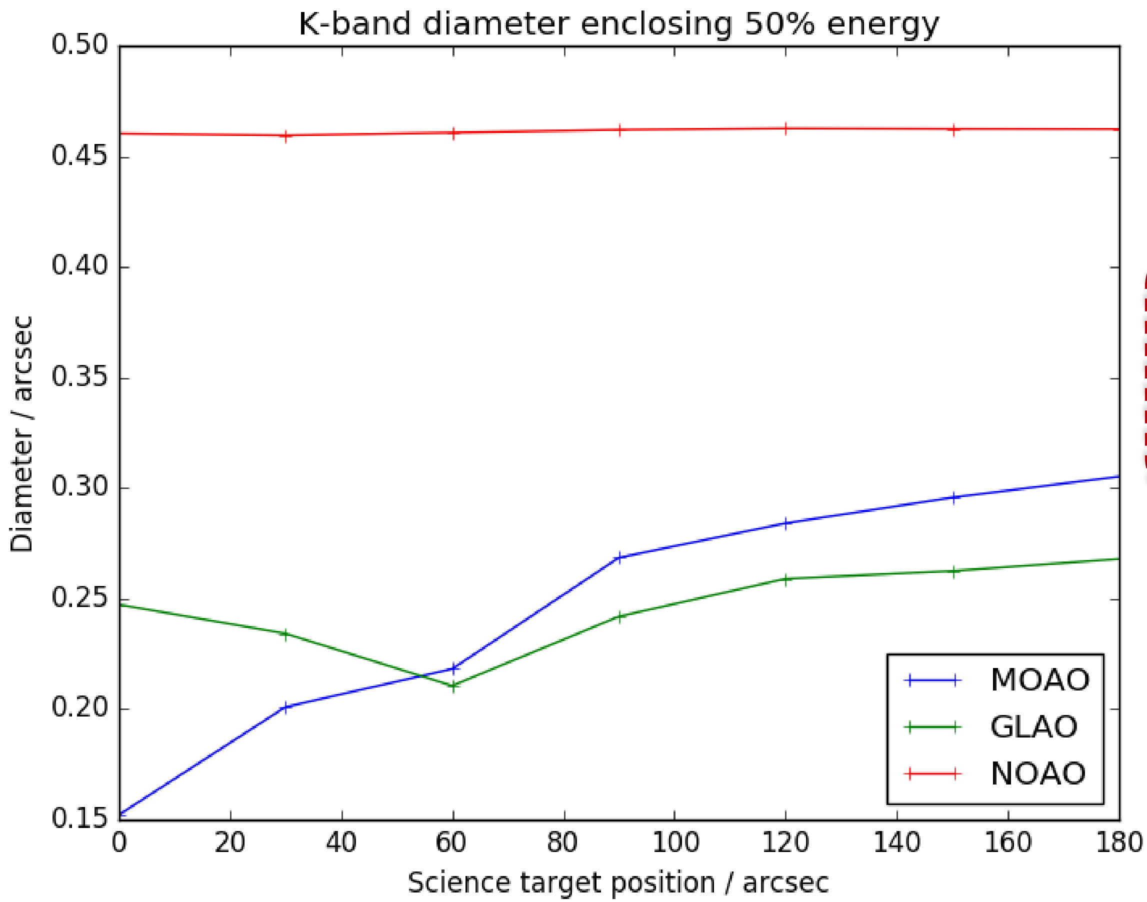
- Simulations performed to provide estimates of potential GLAO/MOAO performance
- 0.80" seeing conditions taken from AOF profiles
- 4 LGS at a distance of 90km
- 40x40 subapertures WFS running at 500Hz
- Haven't included NGS explicitly. TTF measured from 'perfect' LGS
- 41x41 actuator deformable mirror in place of adaptive secondary
- All simulations performed in open-loop
  - Less of an issue in simulation with perfect alignment

LGS asterism diameter

On-axis 50% EE diameter for different LGS radii
0.8” seeing, 69% turbulence at ground



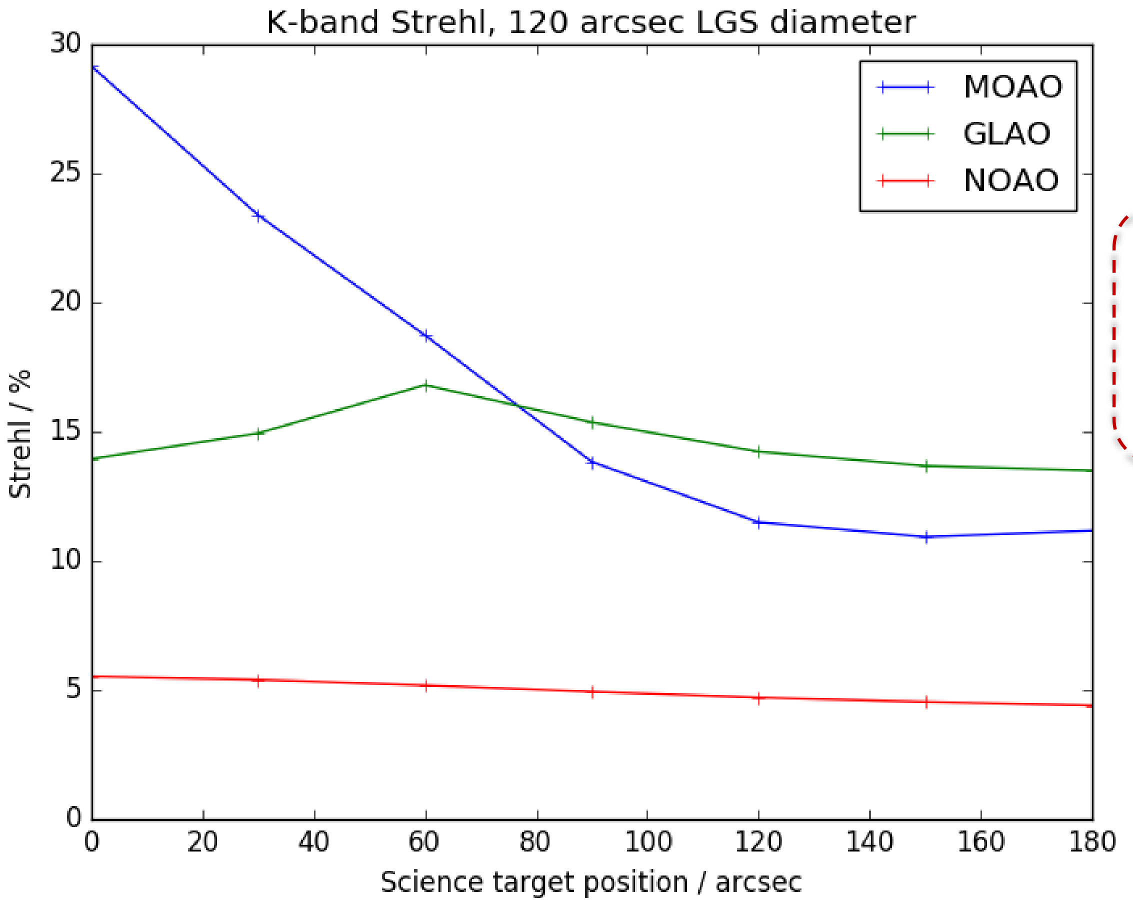
Mixed GLAO/MOAO



Ground layer dominated profile!!

EE across the field for 120” diameter LGS asterism
Strong ground layer means GLAO & MOAO similar

Mixed GLAO/MOAO



Ground layer dominated profile!!

Strehl across the field for 120” diameter LGS asterism

Conclusions

- Open-loop LGS/NGS MOAO has been demonstrated on-sky at 4m and 8m scales
  - LTAO = MOAO with an LGS asterism optimised for a single direction
- Wide-field MOAO performance dependent on asterism diameter and turbulence profile
  - Including a 5th LGS or using off-axis bright NGS would increase the MOAO field significantly
  - Need more information on high-altitude turbulence variation
- 4LGS MOAO deployed on the VLT can provide simultaneously:
  - Wide-field GLAO providing a 2-3x improvement in 50% EE diameter across a 7’ (or larger) diameter field
  - Narrower-field MOAO with additional gain over GLAO within a central 1-4’ diameter region
- KMOS upgraded with MOAO channels within a central region would be a instrument that would match this configuration