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Wide-field Adaptive Optics for MOSAIC

The multiple object spectrograph for the (E-)ELT

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- and -

The MOSAIC consortium

Also: Vienna, Stockholm, Helsinki, Roma, Arcetri, Madrid, Geneva

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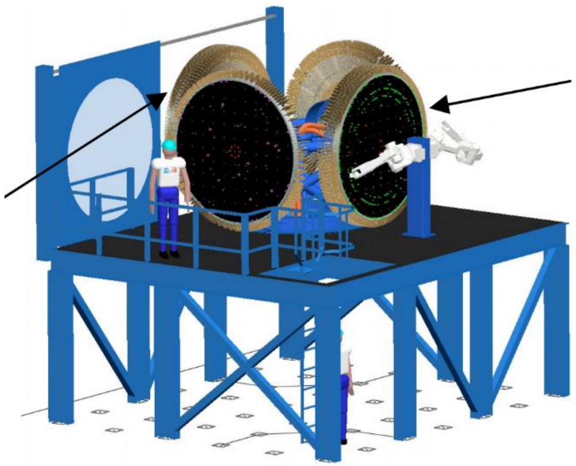
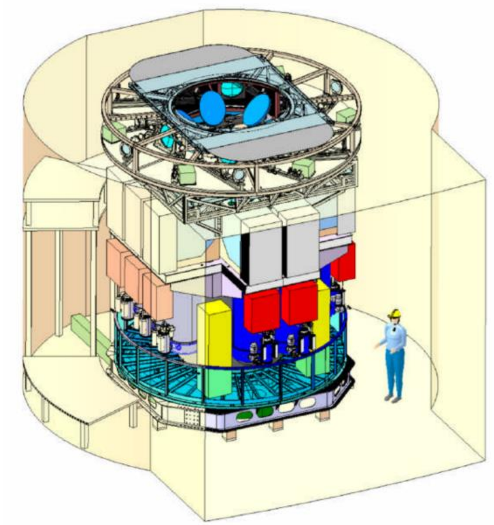
A little bit of history…

- Combination of two phase A MOS instrument studies (from 2009)
  - EVE – A 200+ channel seeing-limited VIS fibre-based MOS
  - EAGLE – A 20 channel NGS/LGS MOAO NIR IFU MOS
- 2 very different instruments but with several overlapping or complementary science cases
- Only a single MOS planned for E-ELT initial instrument suite
  - Would the combination of EAGLE and EVE in a single instrument enable better and more efficient observations?
- MOSAIC phase A started in late 2015
  - Runs until the end of this year





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From Science Cases to Observing Modes

- **Science cases combined to provide 4 observing modes**
- **High-definition mode (HDM)**
  - **10-20 objects observed in the NIR with AO correction**
  - **Coarse sampling IFUs with ~2x2 arcsecond fields of view**
- **High-multiplex mode (HMM)**
  - **As many objects as possible with ~seeing-limited spatial resolutions at VIS and NIR wavelengths**
- **Intergalactic medium (IGM)**
  - **10-20 visible wavelength 'light buckets' for IGM tomography**
- **A fibre-fed MOS was selected the only option that could support multiple modes within the budget**

High Definition Mode (HDM)		MOAO or GLAO
IFU field of view	2.0 x 2.0 arcsec	
Multiplex	10 (no maximum)	
Spaxel sampling	80 mas	
Ensquared Energy	25% (30%) within 2 spaxels	
Wavelength coverage	1000-1800 (800-2500) nm	
Field of view	40 (78) arcmin^2	
High Multiplex Mode (HMM)		GLAO or No AO
On-sky aperture	0.84" VIS/0.5" NIR	
Multiplex	200 (no maximum)	
Wavelength coverage	400-1800nm	
Field of view	40 (80) arcmin^2	
Ensquared Energy	Undefined	
InterGalactic Medium (IGM)		No AO
IFU field of view	3.0 x 3.0 arcsec	
Multiplex	10 (30)	
Spaxel sampling	0.3"	
Wavelength coverage	400-800 (370-1000) nm	
Field of view	40 (78) arcmin^2	
Ensquared Energy	Undefined	

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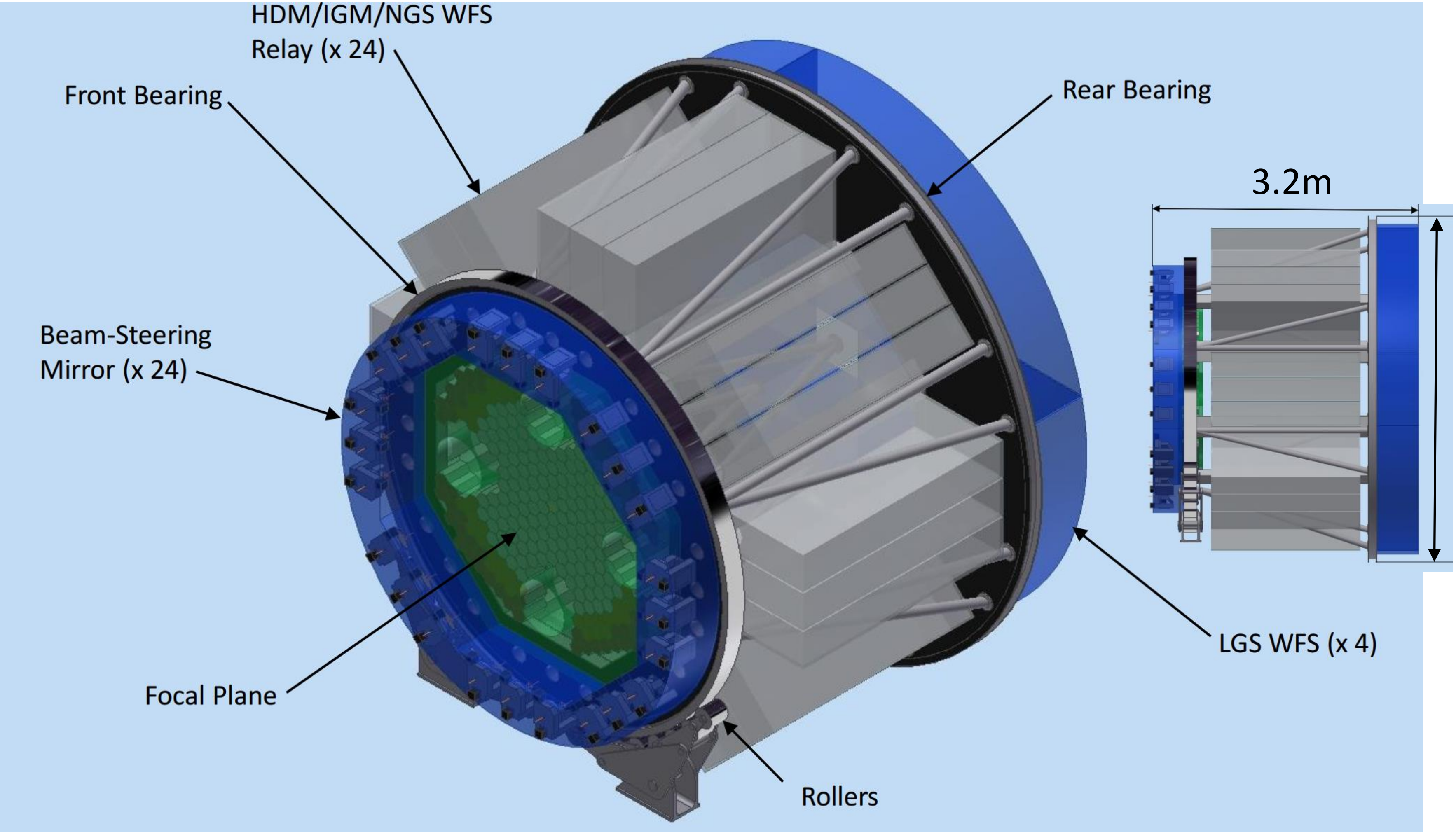
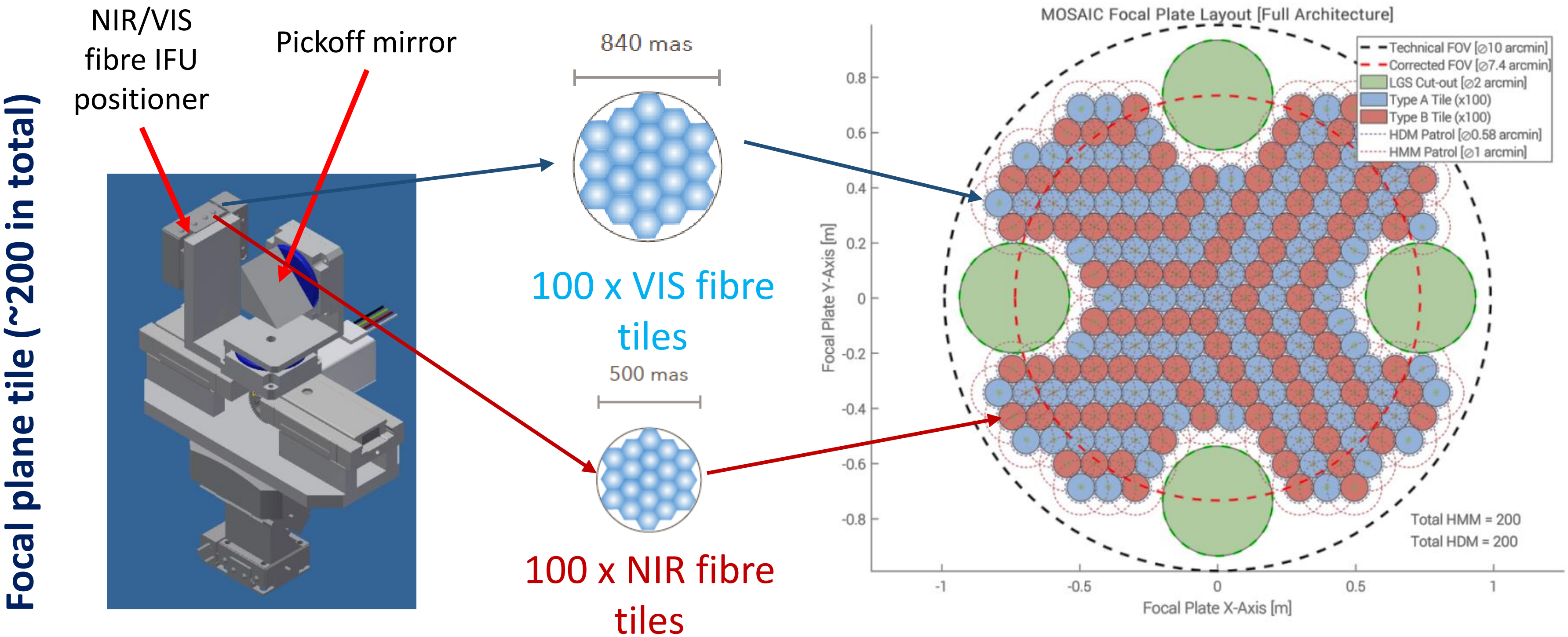
The AO challenges

- Is there a system architecture that can support 4 instrument and 2 AO operating modes in a single focal plane?
- Can we provide sufficient levels of correction across such a wide field of view?
  - H-band 27.5% ensquared energy within 160mas for MOAO mode
- How can it be implemented at the E-ELT?

MOSAIC design



MOSAIC tiled focal plane – Fibre positioning



- **Tile diameter of 1 arcmin**
- **Tile can deploy either fibre or mirror to centre of adjacent tile**

- **Tiles arranged to provide 100% field coverage for both NIR and VIS fibres**

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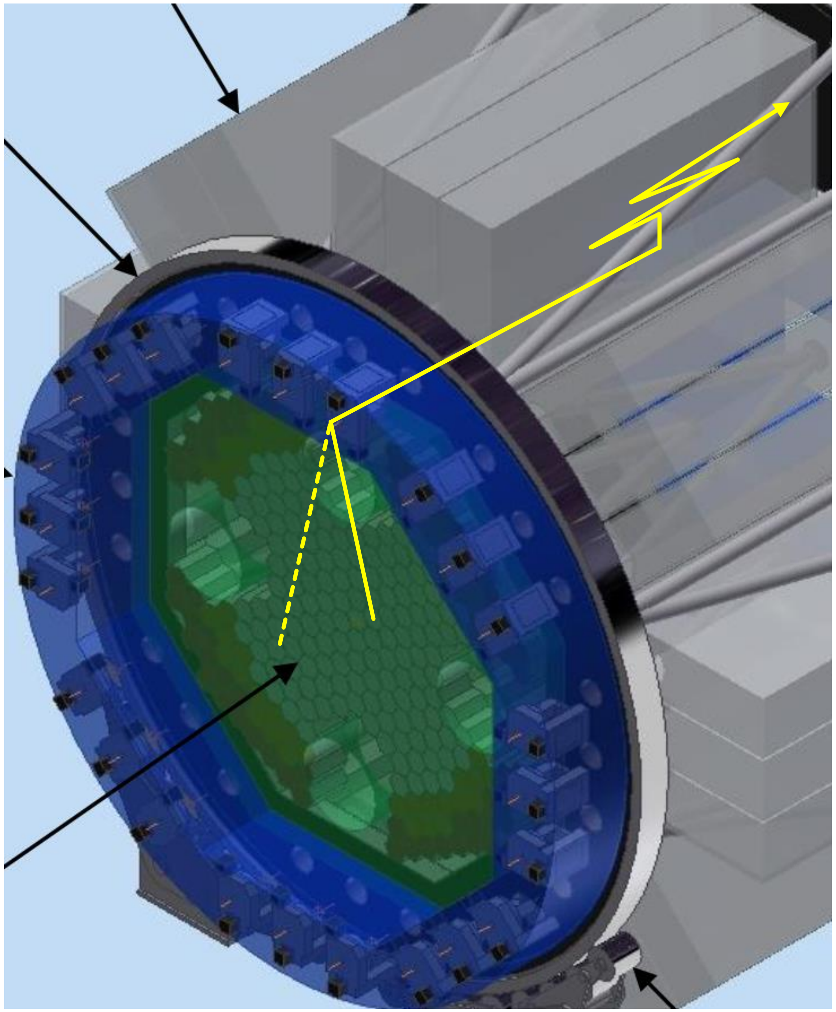
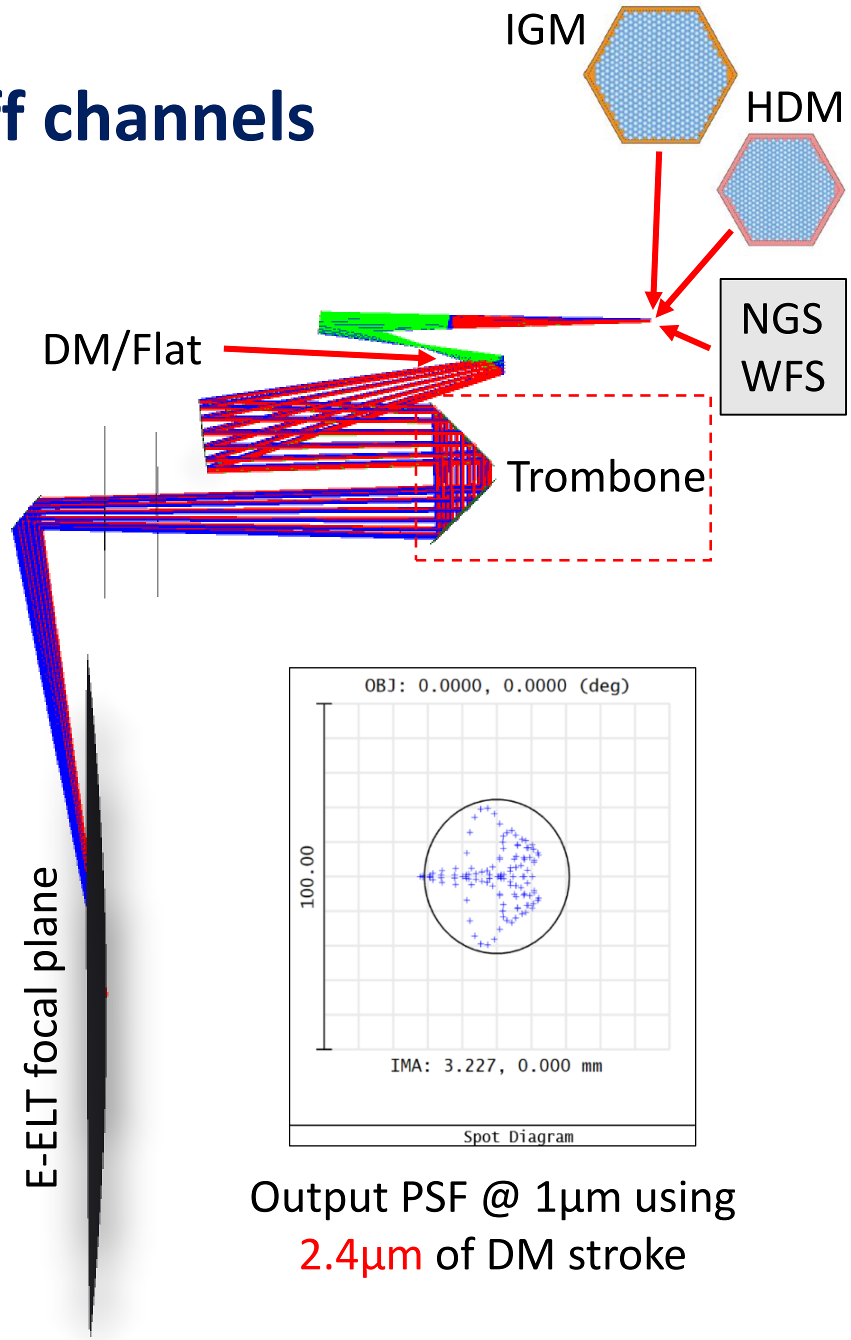
MOAO/NGS WFS pickoff channels





Output PSF @ 1µm using 2.4µm of DM stroke

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Baseline AO simulations

- **Initial baseline from the EAGLE MOAO study**
  - **EAGLE MOAO system provided 30%EE H-band EE within 75 mas**
- **How far can we reduce performance/cost and still meet HDM EE requirements?**
  - **Minimum of 3 NGS WFS to drive telescope**
- **How does the ELT AO system perform over its full FoV?**

Parameter	EAGLE Value
Number of LGS	6
LGS subapertures	74x74
LGS asterism diameter	7.4’
Number of NGS	5
NGS subapertures	74x74
M4 actuators	75x75
MOAO DM actuators	64 x 64
Frame rate	250Hz
r_0	8.9 - 15cm
Turbulence profile	ESO 35 layer model(s)

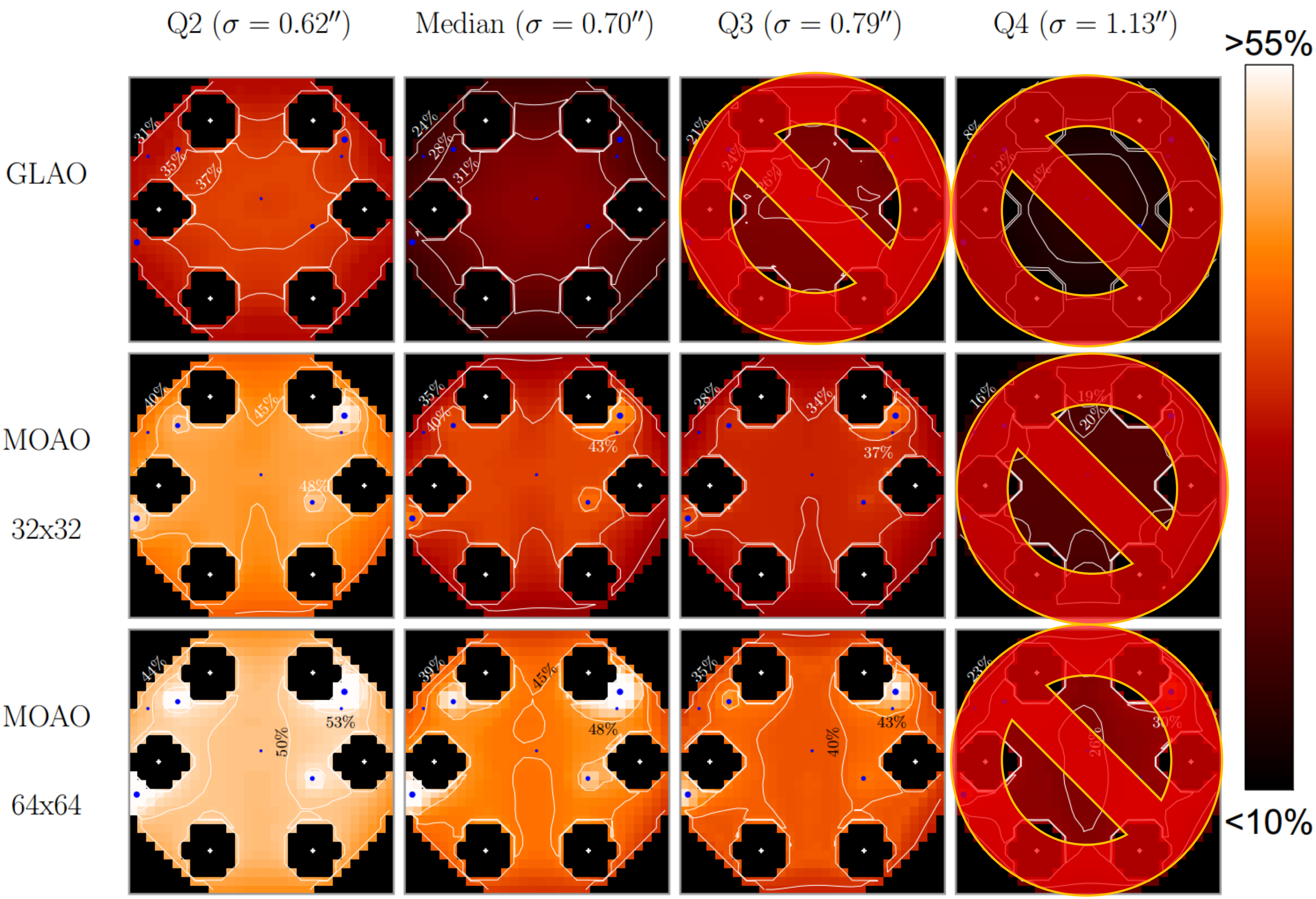
Step 1: Cut the number of actuators

6 LGS — Asterism F2 — $\lambda = 1.65\mu m$ — boxsize= 150mas

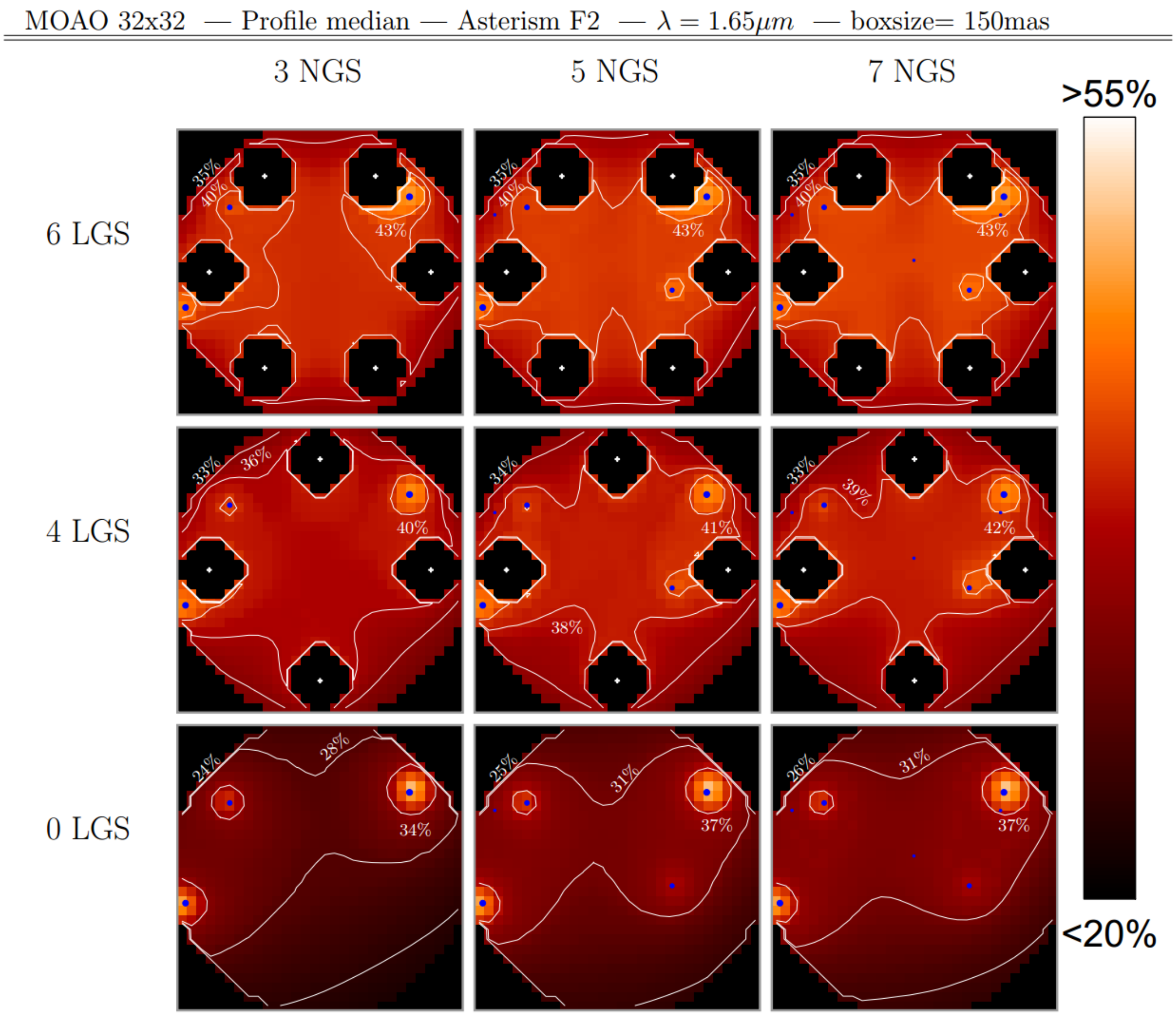
ELT M4 (adaptive 'secondary') only

M4 and a 32x32 actuator MOAO DM

M4 and a 64x64 actuator MOAO DM

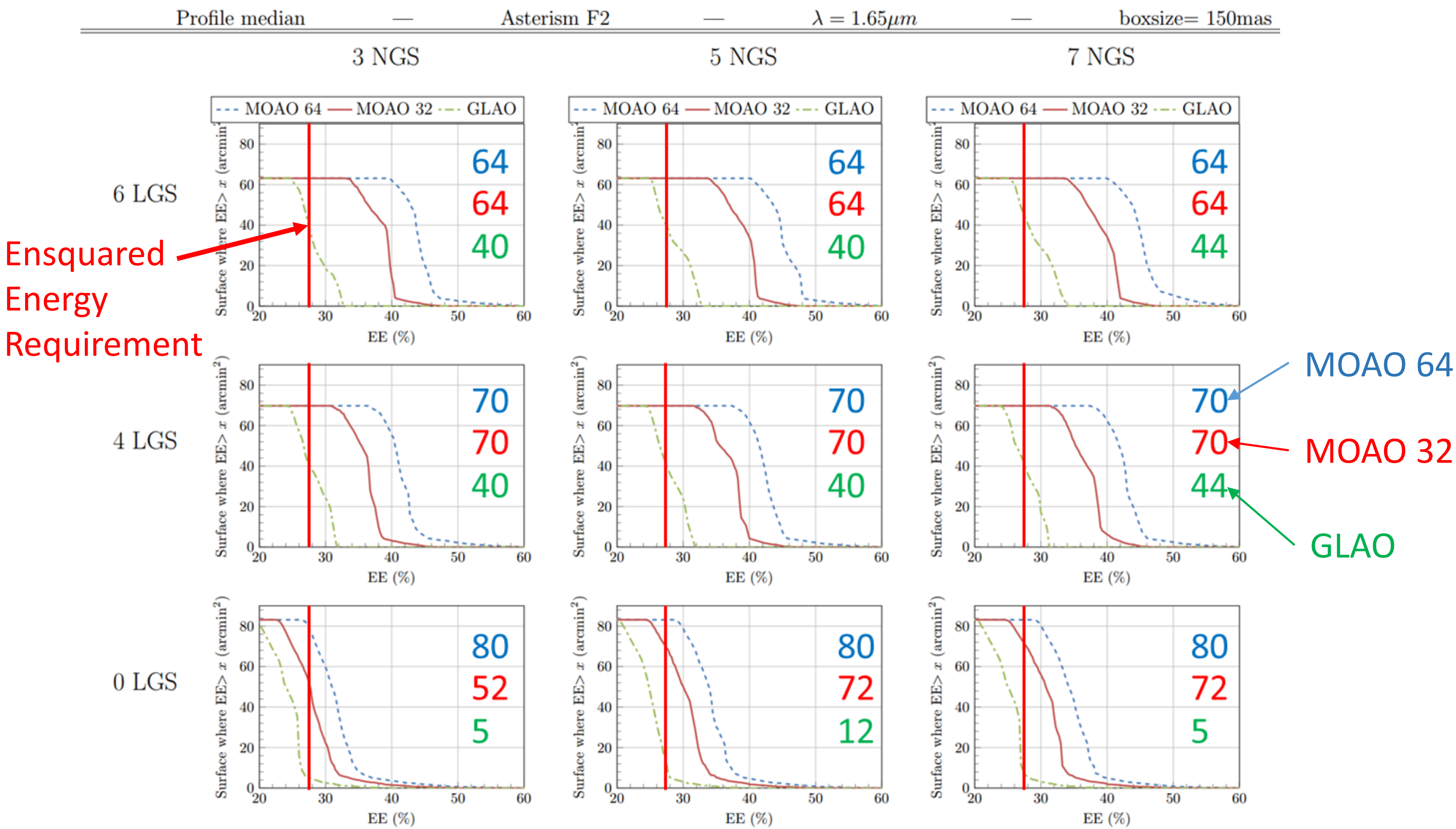


Step 2: Get rid of WFSs



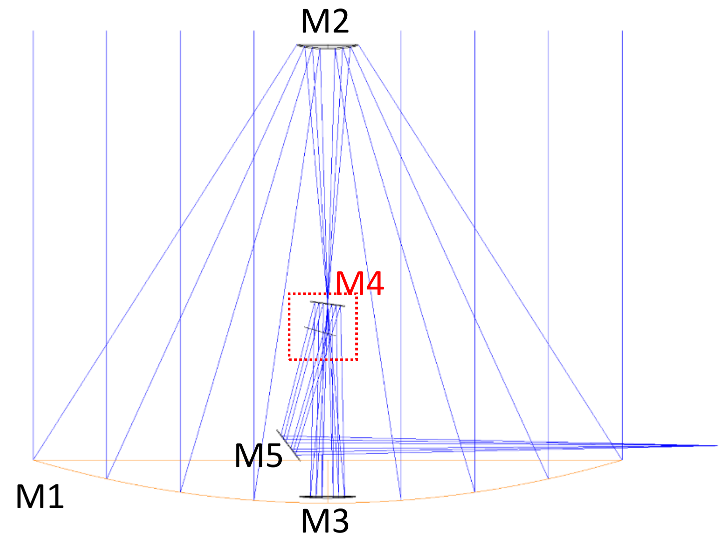
MOAO corrected field of view

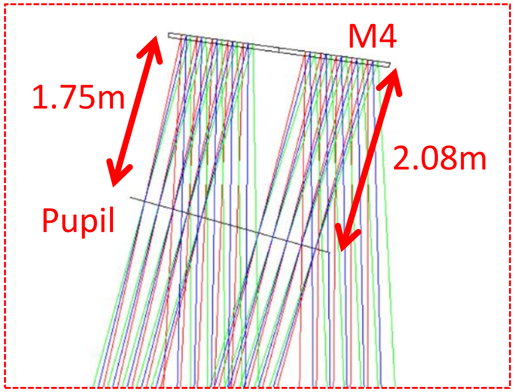
40 arcmin^2 requirement (80 goal)

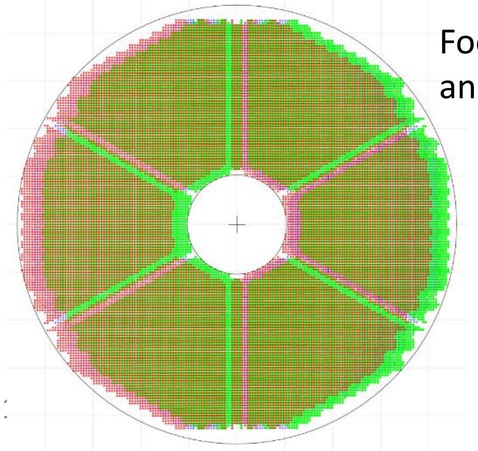


ELT Adaptive Mirror conjugation

- **ELT M4 is conjugated to a mean altitude of 612m**
  - **Corresponds to a ±1.75% pupil shift across a 7.4' FOV**
  - **Significant fraction of an actuator spacing**
- **Impacts both MOAO and GLAO operating modes**
  - **Required MOAO actuator density increases**
  - **GLAO correction degrades**

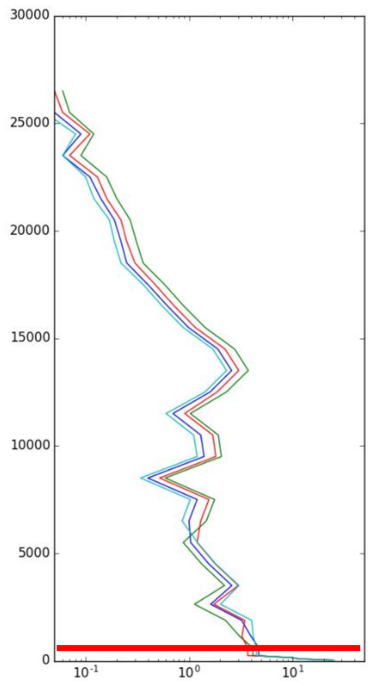


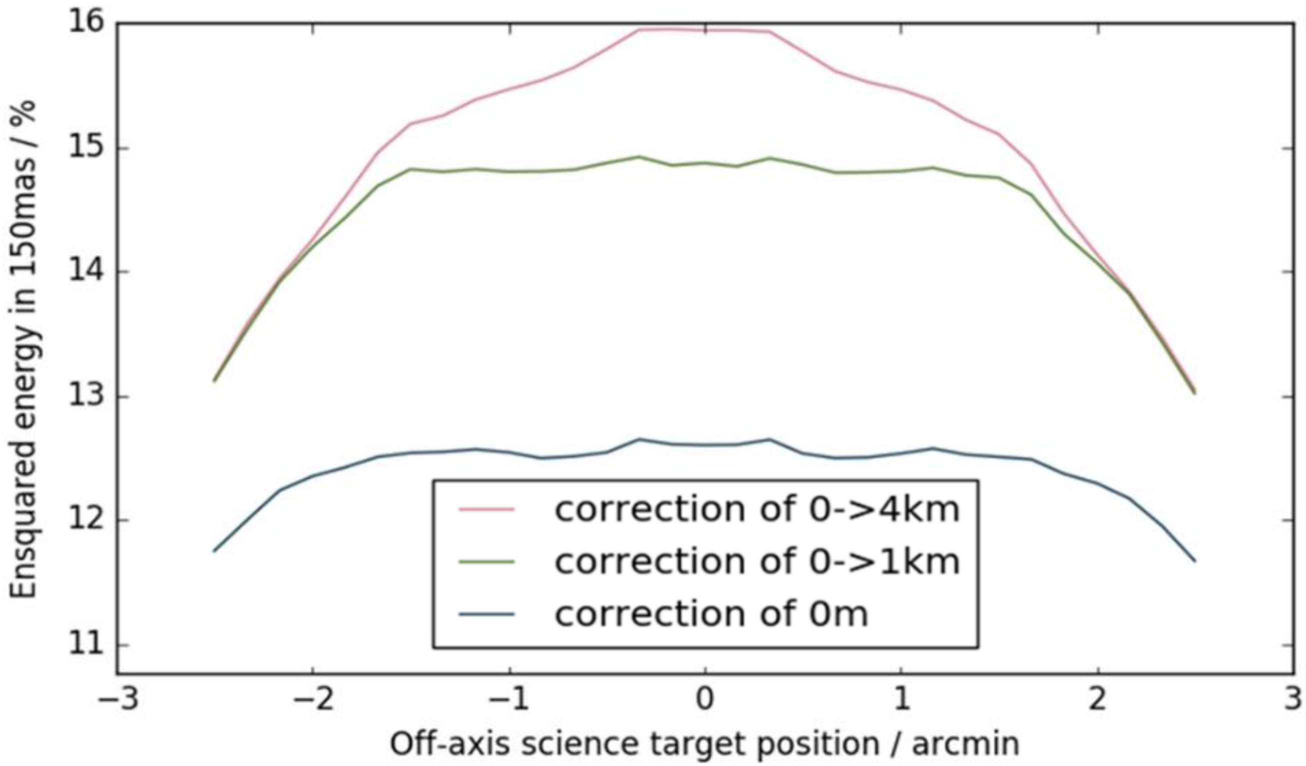




Footprints at 0' and ±5' at M4

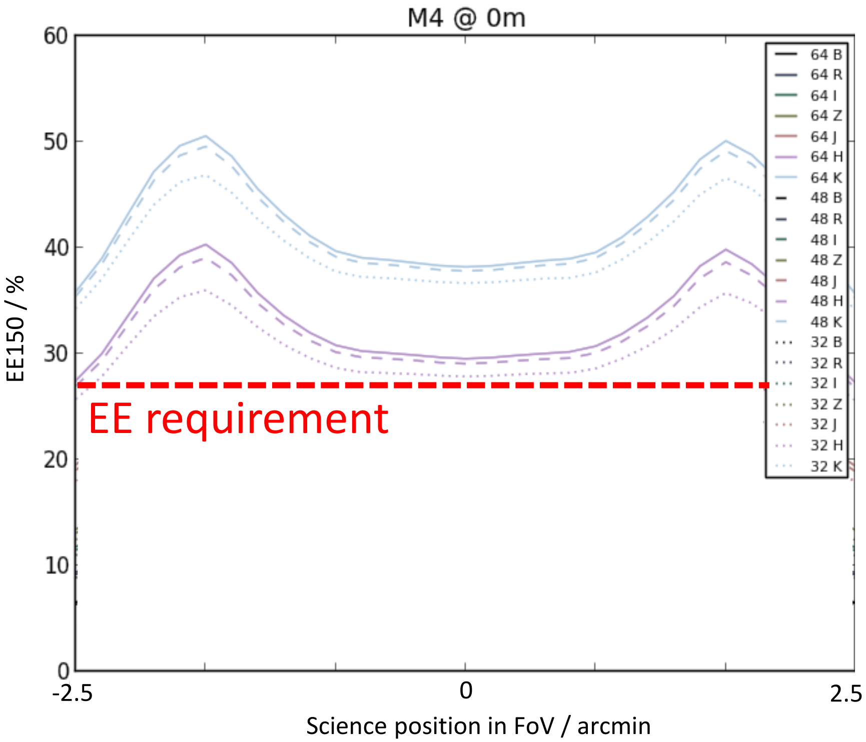
ELT M4 Conjugation – GLAO

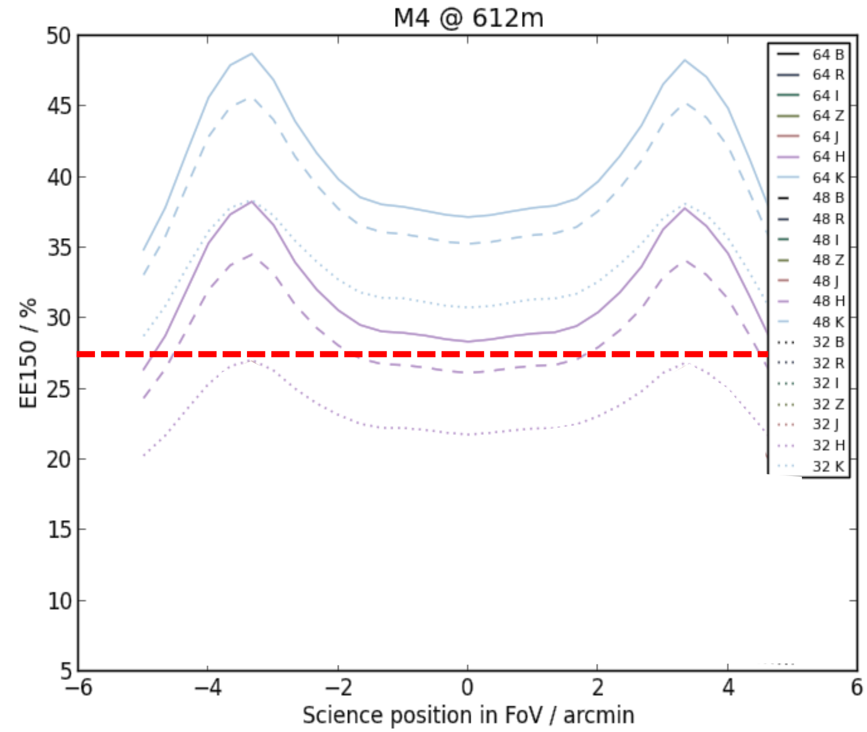




- **ELT M4 conjugation equivalent to an anisoplanatism error**
- **Corrected GLAO FOV limited to a few arcminutes diameter**

ELT M4 conjugation – MOAO actuator count

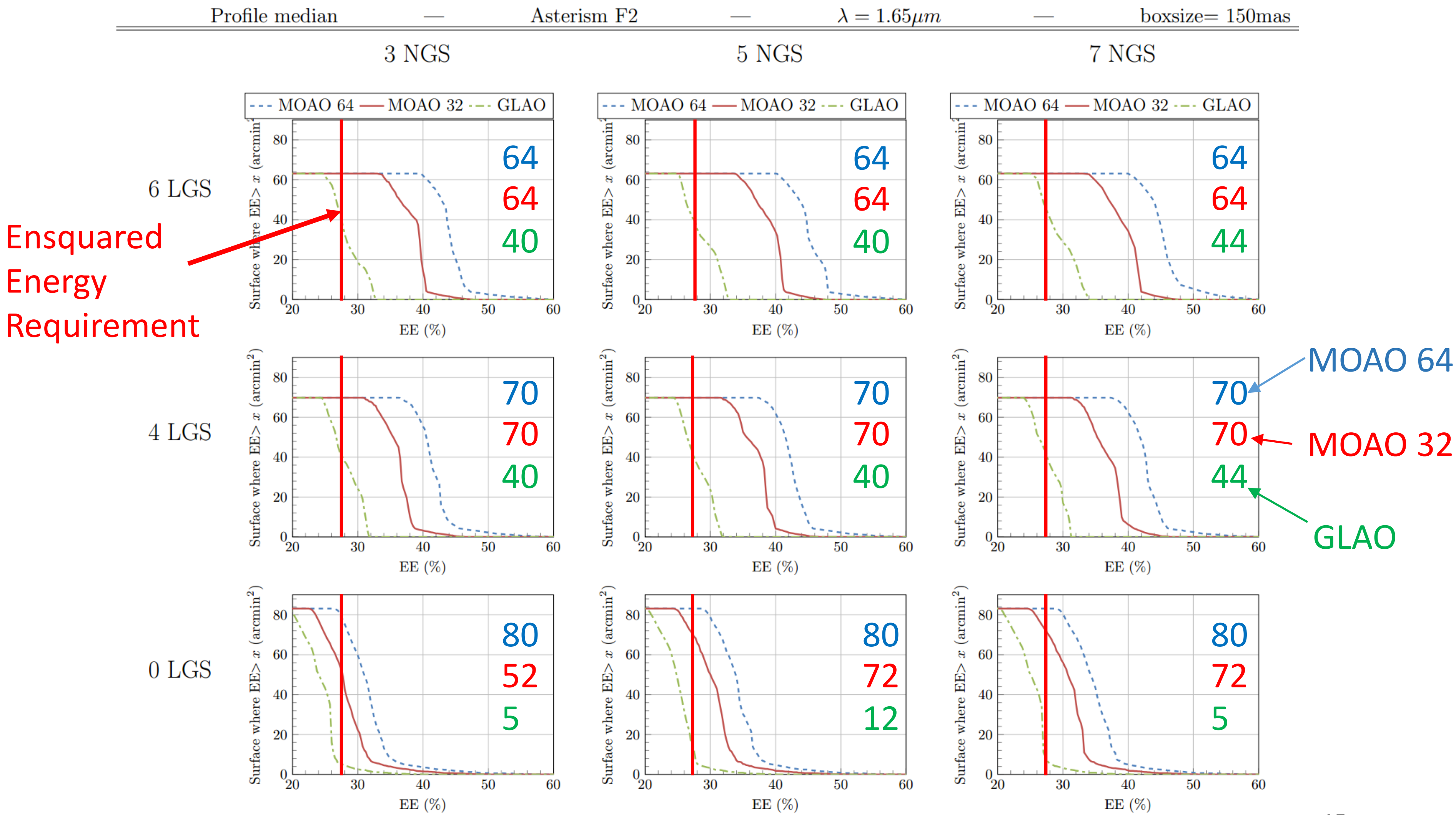




- **Independent Monte-Carlo simulations of H-band 150mas EE with a conjugated M4**
  - **Overall performance slightly lower than earlier simulations**
  - **Central 9-10% EE dip is a reconstructor artefact optimising correction at LGS radius**
- **Conjugation to 612m drops 150mas EE by 4-5%**
  - **Requires increase in number of MOAO DM actuators beyond 32x32**
  - **Between 32x32 and 48x48**

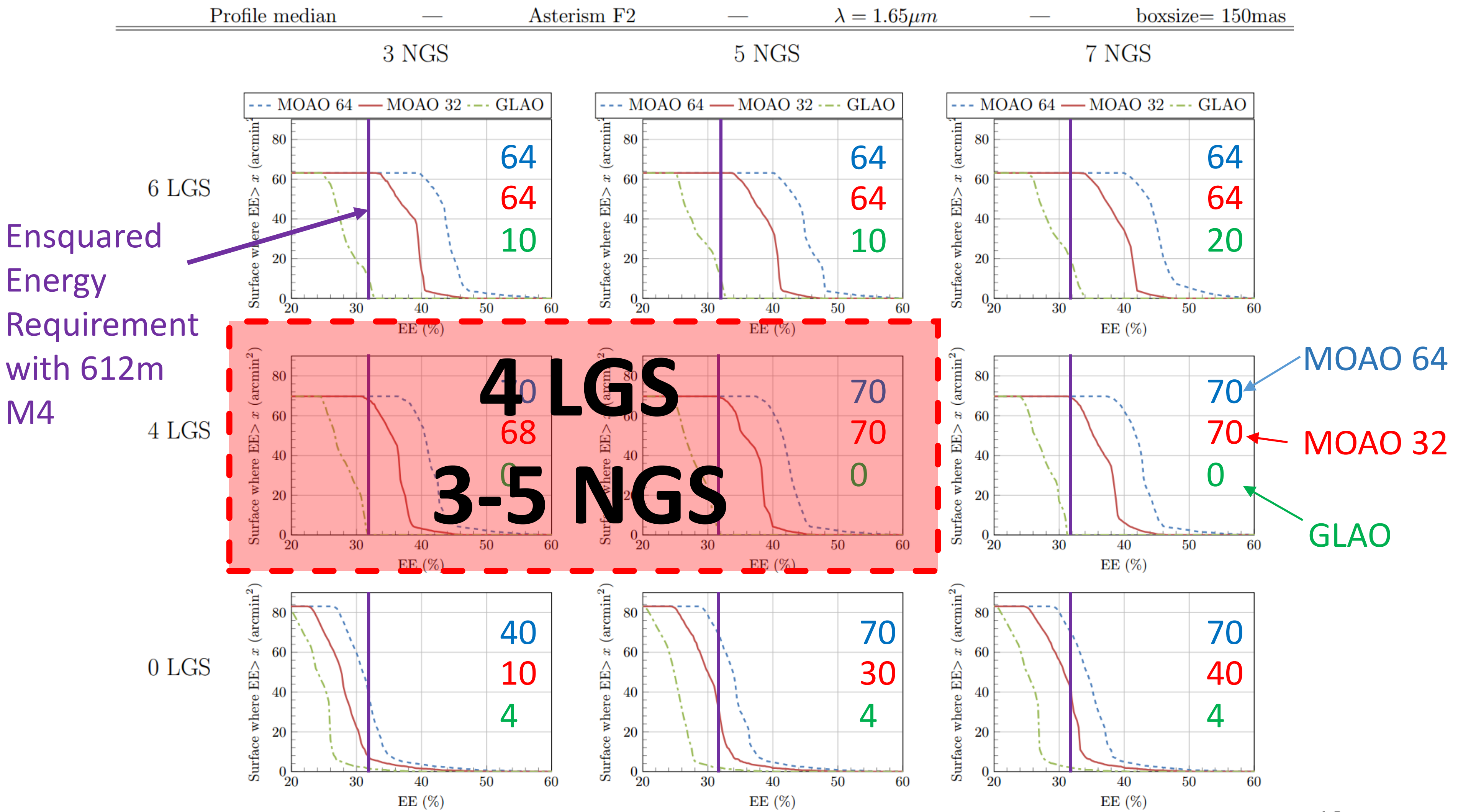
MOAO field of view

40 arcmin^2 requirement



MOAO field of view

40 arcmin^2 requirement



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Final system parameters

- >7.2’ diameter corrected field of view
- 4 LGS and (up to) 4 NGS
  - Allowed us to observe every real cosmological field we’ve tried
- 10 MOAO IFU channels
  - H-band EE > 27.5% within 150mas
  - 4000 x 80mas spaxels
- GLAO/Seeing modes:
  - 100 NIR channels
  - 100 VIS channels
- Spectra @ R=5000-18000 from 400-1800nm

Parameter	Baseline value	MOSAIC value
Number of LGS	6	4
LGS subapertures	74 x 74	74 x 74
LGS asterism diameter	7.4’	7.4’
Number of NGS	3-7	4
NGS subapertures	74x74	64 x 64
M4 actuators	75 x 75	75 x 75
MOAO DM actuators	64 x 64	40x40 (TBC)
Frame rate	250Hz	250Hz
r_0	8.9 - 15cm	8.9 – 15cm
Turbulence profile	ESO 35 layer model(s)	ESO 35 layer model(s)

Conclusions

- **Is there a system architecture that can support 4 instrument and 2 AO operating modes in a single focal plane?**
  - **Yes, a mosaic of tiles**
- **Can we provide sufficient levels of correction across such a wide field of view?**
  - **Yes, but M4 conjugation will limit GLAO FOV**
- **How can it be implemented at the E-ELT?**
  - **8 WFS, 200 tiles, 4000 fibres, 18000 actuators, 220 IFUs, 9 spectrographs and 2 giant bearings**